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MODELING SPACE IN THE AIR FORCE COMMAND
EXERCISE SYSTEM (ACES)

THESIS

Robert Payne Jr., Captain, USAF

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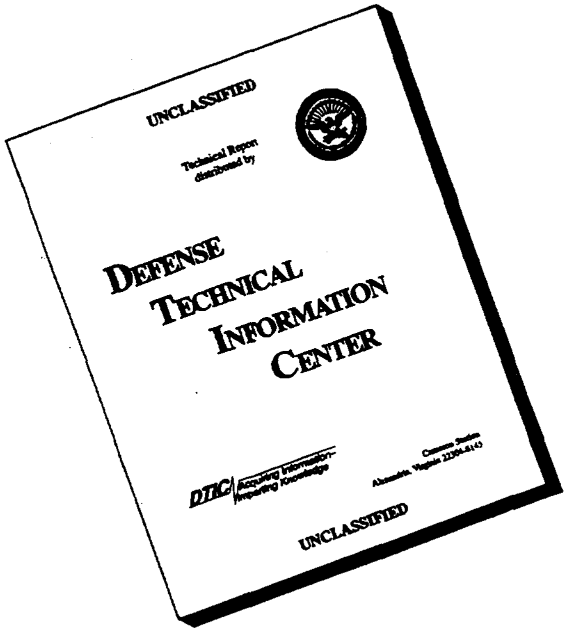

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MODELING SPACE IN THE AIR FORCE COMMAND EXERCISE SYSTEM (ACES)

THESIS

Presented to the Faculty of the School of Engineering

Air Education and Training Command

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Operations Research

Robert Payne Jr., B.S., M.S.

Captain, USAF

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Robert Payne Jr.

Table of Contents

List of Tables

Table Page(s)

List of Figures

AFIT/GOA/ENS/96M-04

Abstract

In response to the increased influence of space forces on today's battlefield, several theater level models were analyzed for the presentation of space forces. These models were the Extended Air Defense Simulation (EADSIM), the Joint Theater Level Simulation (JTLS), the Integrated Theater Engagement Model (ITEM), the Tactical Warfare Model (TACWAR), Thunder, Janus, and the Aggregate Level Simulation Protocol (ALSP). While ALSP is not a model but a simulation protocol connecting various models, it was studied because it appears to be the future of modeling.

The consensus of the analysis was that space forces are virtually ignored by most of the models and when space was considered, the dynamic nature of the systems involved were not captured.

The Air Force Command Exercise System (ACES) was chosen to determine how the effects of space forces can be implemented into theater level models. ACES is a discrete event combat simulation designed to support intermediate and senior service schools in teaching Air Force doctrine within the context of a theater warfare exercise. Its primary focus is to allow specific educational goals to be taught. This research focused on both the present modeling of space forces within widely used theater level models and a methodology to incorporate space forces into models that lack the influence of space.

The Gulf War exposed how important functions performed from space can be to the success of a combat forces. Because of the practicality of space's influence, a picture of today's battlefield that does not include space forces is incomplete.

THESIS APPROVAL

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MODELING SPACE IN THE AIR FORCE COMMAND EXERCISE SYSTEM (ACES)

I. Introduction

Space Background

Since the launch of Sputnik on 4 October 1957, the United States has realized the strategic importance of space. President Eisenhower made the first official statement that space was of military significance in 1958 to the science advisory committee. He stressed that the development of space technology, in addition to being required by human curiosity, scientific knowledge, and the maintenance of national prestige, was important for the "defense of the United States." Congress followed up on the President's sentiment in House Resolution 1770.

> This country is not unmindful of what these Soviet achievements (in space) mean in terms of military defense...Ballistic missiles already travel for a considerable part of their path through near outer space and can arrive virtually without warning to deliver their devastating thermonuclear warheads. The United States must have a strong capability in the use of outer space, both as a deterrent to military use of space vehicles against this country and as an aid in developing antimissile techniques. Satellite (operations) will have important implications for guarding the peace. On the one hand, they are adjuncts to weapon systems related to the deterrent power, and, on the other, they represent techniques for inspection and policing, in accordance with any disarmament scheme which may be negotiated in the years to come (6: Sec15,5).

Government agencies developed a variety of space plans to respond to the strategic use of space. In 1961, Secretary of Defense Robert McNamara assigned all space research and development projects to the Air Force. Though this decision was modified in 1970 to permit assignment of responsibility for space programs on a case-by-case basis, the

decision catapulted the Air Force into a leadership position in all areas of military space systems (6: Sec 15,10).

The Air Force space plan evolved to treat space as a place and not a mission. Therefore, as with land, sea and air, the systems deployed in space have the potential to perform or support combat missions. These missions fall into four broad categories: space control, force application, force enhancement, and space support. Historically, military space power has concentrated on combat support missions, specifically force enhancement-type missions as opposed to performing combat tasks. Force enhancement includes the tasks of communications, environmental observation, reconnaissance/surveillance/intelligence, missile warning, and navigation (6: Sec15,11-12).

Military operations have grown more reliant on space forces as time has progressed. These resources were brought to bear in 1991 during Desert Shield/Desert Storm. Commonly called the 'First Space War,' the Persian Gulf War was the first time space systems functioned not just at the strategic level, but at the operational and tactical levels of war as well. Space-based assets dramatically effected the ability of the operational level commander to successfully plan and prosecute a comprehensive warfighting plan. This point is highlighted by the fact that 85 percent of the total inter- and intra-theater communications traveled through communications satellites. Nevertheless, without a clear space doctrine, tactical commanders had to use ingenious adaptation, resourcefulness, and ad hoc procedures to insure that space assets truly supported both the personnel engaged in combat and the decision makers. The luxury of a six month buildup before hostilities began also aided in the success of the space force

employment. Theater planners diligently studied the space environment, removing shortcomings to better prepare themselves for the impending conflict. As world tensions grow, theater commanders and space resources alike must be ready to react at a moments notice (9).

Wargaming

A wargame, or combat model, is a simulated military operation involving two or more opposing forces and using rules, data, and procedures designed to depict an actual or hypothetical real-life situation. These models are used to study military planning, organization, tactics or strategy (33:15). Wargames are categorized by either their purpose, qualities, or construction. The purpose of a combat model is generally described as analysis or training and education. To classify a model by its qualities, an analyst can study the domain, span, environment, force composition, scope of conflict, mission area, or level of detail of processes and entities of the model. Classification by construction requires the design of the model be studied. The construction of a wargame breaks down into human processing, time processing, treatment of randomness, and sidedness (8:3-11). This study will focus on both two-sided, analytical and educational models spanning the theater.

Space in Wargames

Many of today's widely used theater-level models were designed before space forces took a prominent role in the conduct of a battle and therefore do not take into account the effect space resources have on the outcome of a campaign. While many of the functions performed by space-borne assets are simulated by several wargames, these functions are generally performed by terrestrial or air forces. If space forces are

modeled, quite often orbital mechanics and environmental effects are ignored. To make more informed decisions, military leaders, analysts, and strategists must not just consider the terrestrial battlefield, but also the space above that battlefield. Therefore, the models they use must reflect this change.

Problem Statement

Theater level models currently used for analysis and wargaming are deficient in the representation of space forces. As warfighting changes, these simulations need to more accurately reflect today's battlefield. At the same time future theater commanders must be educated on the importance of space resources to campaign planning so that they will be ready to fight the next war. This research investigates incorporating the effects and influence of space systems in the Air Force Command Exercise System (ACES). This model, which currently models land, sea, and air forces, aids in the education of Air Command and Staff College (ACSC) students planning a theater-level campaign and employing the principles of war. In the course of this investigation, the following questions will be answered:

1. What do Air Force leaders need to know about space?
2. How are space systems currently being modeled in theater level simulations?
3. What can be extracted from other models to incorporate into ACES?
4. What is the best way to incorporate space into existing campaign models?
5. How should this information be passed to wargame players?

Once these questions are answered, this thesis will be presented to programmers at the Air Force Wargaming Institute (AFWI) to be used as a guide to develop the necessary space module(s) to be run with the ACES game.

Methodology

The solution of this problem is a two-pronged effort involving both changes to the ACES model and the way ACSC students are taught about the benefits of space. Either of these issues addressed without support of the other will impede the learning process. Both must be done so that all U.S. forces, land, sea, air, and space, will be prepared for the next conflict regardless of its scope or location.

The more complex of these two solutions is the ACES computer simulation. There are three methods of incorporating space assets into a combat model. The first solution is the creation of a space model that would process the interactions of space assets over the battlefield and feed the necessary information into a separate combat simulation. This model would be highly aggregated to accommodate computer limitations. This high level of aggregation would group space resources together and derive deterministic results. The second alternative is to accurately and completely model every entity in the scenario so that its associated details are incorporated in the scenario. The third option is modeling the entire system following a convention of multiple levels of representation such that the entities are hierarchically modeled at varying levels of detail (27:2-3). The third option has been chosen for this particular research activity.

In 1979, Lt Col (then Major) Glen Harris of the (then) Aeronautical Systems Division introduced the concept of a "validated analytical hierarchy of models" in order to analyze the force effectiveness within a simulation environment. In a paper on the subject, he noted:

> Neither a highly detailed approach nor a broad aggregate approach by itself is adequate to analyze the complex battlefield. Unless both approaches are used and carefully integrated, the results obtained will not provide the insight required to determine why one ensemble of systems should be preferred over another (27:6-7).

This statement provides the basis for adding more detail to any combat model.

This approach applies to the inclusion of space in campaign level models. Once a model is determined to be deficient in respect to modeling the impact of space, decisions must be made on what space-borne assets need to be added and how to infuse these systems into the model. The solution as suggested by Lt Col Harris is a mixture of model integration and model aggregation. Model integration is the run-time invocation of a more detailed model when its level of detail is required. This process is similar to a subroutine call. Model aggregation refers to the intelligent capture of the essence of a model without all the detail of that model. The technique known as 'metamodeling' is a statistically-based method to reduce the complexity of a detailed model to a satisfactory mathematical representation of that model, using only the most critical elements. Other, less statistically robust techniques for incorporating the results of detailed models involve exhaustive simulation runs, look-up tables, performance curves or other response trends. These results can then be incorporated in other models (27:5-6). These processes have been researched and tested in several other applications and will be explored for their applicability for this situation.

The infusion of space into simulations will aid in the analysis of weapon procurement, deployment, and employment. However, lack of knowledge on the part of operational commanders as to what capabilities space assets provide and how best to exploit them will prevent the most efficient use of space forces in future conflicts. This

additional knowledge will have to come from a variety of sources, to include participation in the ACES wargame at the Air Force Wargaming Institute. The incorporation of space assets into an academic wargame, such as ACES, can educate military personnel on the employment of space systems leading to a successful conflict outcome (33:2-3). Therefore, use of ACES must support specific learning objectives to form a cohesive educational unit that will help expand the view of future theater leaders beyond terrestrial forces.

Research Issue/Question/Result

The following results will be achieved when this project is completed and the questions in the problem statement are answered:

1. A review of current space modeling activities
2. A review on how space could be modeled
3. Pseudocode for space functions to be incorporated into the ACES model

Scope

The scope of this research will center on how to best represent space forces in the ACES wargame model and the type of education ACES should provide for the game players. What space-borne assets offer the warfighter and how these effects are currently being modeled in theater level combat models will be discussed. Finally, this effort will explore model integration and aggregation as the primary method of infusing space forces into ACES.

Conclusion

This chapter introduced the history of United States involvement in space and the world of combat modeling including its shortcomings regarding the modeling of space

forces. The issue of educating future warfighters was raised and it will be expounded on in later chapters. Chapter II reviews the literature of works on space forces and space assets in current combat models. Chapter III will addresses a possible method of modeling space within any theater level model. Chapter IV covers the modeling of the effects of space forces in ACES. Chapters V will provide the conclusions and recommendations.

II. Literature Review

Introduction

Exactly what space forces bring to the battlefield is still largely a mystery to many in military service. The cold war secrecy of space systems limited the access to space systems and technology. The effort of United States space forces in Desert Storm somewhat demystified the military use of the medium, leading all the services to push for education about space capabilities and limitations. As space doctrine evolves, technology must be integrated into all levels of warfare, strategic, operational, and tactical, as well as the tools used to prepare terrestrial forces for battle (10:5-6). As modeling and simulation become more important to decisions made in all branches of service, several widely used campaign level models warrant an investigation. While each is acknowledged to effectively simulate the performance of land, sea, and air units, the impact of space forces in the theater is missing. To overcome this shortfall, modelers must make inferences on what effects space forces have on terrestrial combat and how these forces would be employed. This must be done without the benefit of a common, or accepted, space employment doctrine. A general idea on space capabilities and employment concepts can be garnered from the experience received during the Gulf War but even this knowledge is incomplete due to the ad hoc way space forces were utilized. Before space assets can be added to any model, the following questions must be answered:

1. What functions does the military perform in space?

2. What space functions are currently being modeled in the more widely used campaign level models?

3. Can any of the methods in which these functions are modeled [illegible] other campaign level models?

Space Functions and Tasks

The Air Force mission to defend the United States through the [illegible] exploitation of air and space is conducted through the Global Reach [illegible] (GR-GP) construct of Air Force responsibilities (13). The primary roles [illegible] space in this construct are: 1) sustain deterrence and 2) control the high [illegible] contribution that space makes to the GR-GP approach to the Air Force [illegible] summarized in two sets of space roles, control of space and exploitation [illegible] control of space role involves both the space support and space control [illegible] exploitation of space is composed of both the force enhancement and [illegible] functions. These four functions are made up of individual tasks (1:Sec [illegible] hierarchy is displayed in Figure 2-1 (5).

Space support encompasses combat support missions involving all [illegible] launch preparations, as well as the activities involved with deploying and [illegible] systems (1:Sec 15, 12). The deployment and sustainment activities involve [illegible] operations and on-orbit control. Launch operations are those activities [illegible] achieve orbit. On-orbit control is the caretaking and use of the satellite [illegible] in orbit. This typically consists of mission planning, mission control, and [illegible] satellite as well as retrieval of data from the vehicle and performance [illegible]

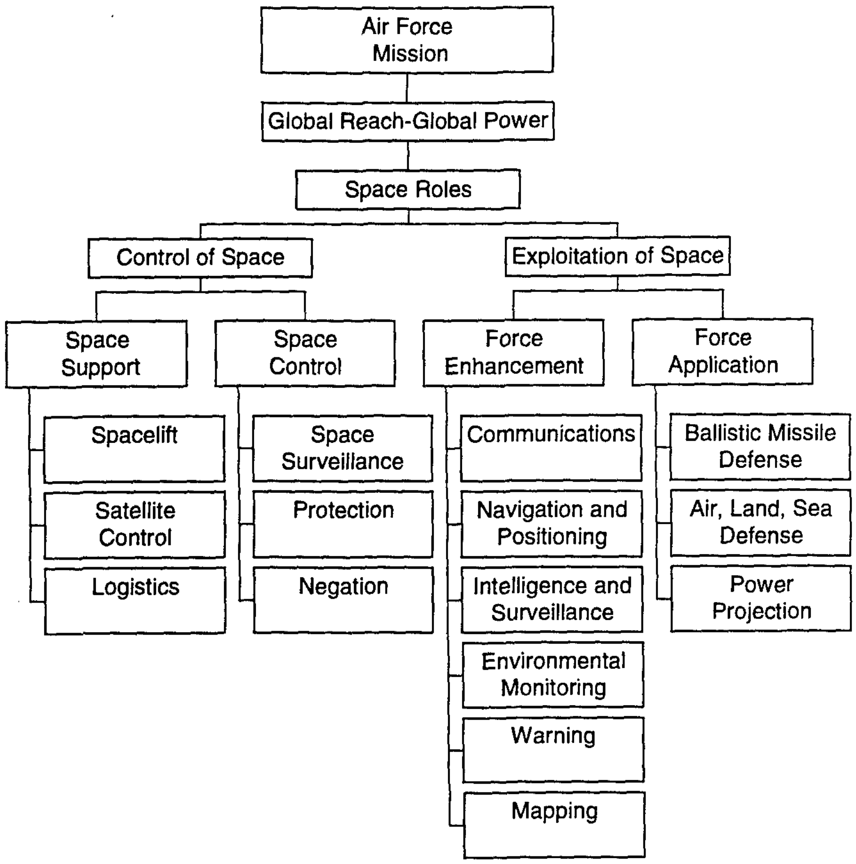

Figure 2-1: Space Functions and Tasks

spacecraft subsystems (33:10). Because the ground stations necessary for the on-orbit control of satellites are vulnerable to air attack and sabotage and satellites cannot be launched on demand currently, space support holds two of the most glaring limitations of space systems (10:6).

Space control incorporates those combat missions that provide freedom of action in space for friendly forces while denying it to an enemy. This function embodies the concept of space superiority and consists of two parts, counterspace and space interdiction. Counterspace operations are those spaceborne or terrestrial operations conducted to gain control and dominance over the space medium. Space interdiction

includes operations against the enemy's space systems that could be used to support operations against friendly space forces (3:Sec 15, 12). Space control will be an important consideration for future conflicts. Theater commanders will have to include in their campaign plans a "means" to attack enemy space assets as well as provide protection for their own space lines of communications. Negation "means" could include jamming satellites, anti-satellite (ASAT) weapons or destruction of ground control sites (13:9).

Force enhancement includes combat support missions by space systems to improve the effectiveness of surface, sea, air, and space forces (1:Sec 15, 12). The tasks supporting this function are communications, navigation and positioning, intelligence and surveillance, weather, warning, and mapping (13). These tasks were the primary contribution space assets made to the U.S. success in the Gulf War (10:3).

Communications

Communications support provided by space systems is divided into two categories, intra- and intertheater communications. Intertheater communications flow from national command authorities to the Joint Force Commander (JFC). Intratheater communications connect the JFC to the squadron-level commanders. Space communication also permits the transfer of imagery and situational awareness to tactical operations and rapid transmission of JFC intent, ground force observations and adaptive planning (28:37). U.S. space communications satellites generally loiter 35000 km above the earth service in geostationary orbits providing continuous communications coverage throughout a prescribed area (11:45).

Navigation and Positioning

Space navigation and positioning enables commanders to determine precise locations of friendly and enemy forces and targets. This task also permits accurate, timely rendezvous of combat forces (28:37). The system that provides this support is the Navstar Global Positioning System (GPS) which provides accurate three-dimensional positional data--latitude, longitude, and altitude--to anyone with a GPS receiver. GPS proved to be one of the real success stories of Desert Storm and stands to grow in importance to the warfighter (10:3).

Intelligence and Surveillance

Intelligence and surveillance is used to identify possible global threats and surveillance of specific activity that might be threatening to US or allied military forces or US territory. Other results of this task are identification of "centers of gravity" in enemy forces and characterization of electronic emissions (28:37). This task is the leading edge to commanders achieving and maintaining "information dominance." Information dominance is the new military buzz-word and is defined as the ability to assimilate all-source intelligence and information on the battlefield, while denying the same ability to our enemy. Information dominance will give the commander "real-time situational awareness" and the ability to "operate with the enemy's intelligence cycle" (10:7).

Weather

Weather support, or environmental monitoring, from satellites provides data on worldwide and local weather systems affecting combat operations (28:37). Through the

use of such systems as the Defense Meteorological Satellite Program (DMSP) satellites, military commanders in theater during Desert Storm were capable of receiving weather data four times a day. DMSP satellites provided meteorologists information to determine ocean surface wind speed, temperatures at various altitudes, amount of water and/or cloud cover, and soil moisture content. With this information, commanders can successfully plan the air and ground campaigns (2:9-10).

Warning

Warning is divided into two categories, strategic and tactical. Strategic warning gives national leaders notice of all possible strategic events, including launch of intercontinental ballistic missiles (ICBM) and their launch locations and impact points. Tactical warning is the use of sensors to detect attacks on US forces in theater (28:37). Despite being designed as a strategic warning tool, the Defense Support Program (DSP) satellite family is the primary system for both categories of missile warning. DSP proved itself in Desert Storm to have more than military importance in that warnings of impending SCUD attacks proved to have significant psychological and political importance. The warning system served both to contain the conflict, by providing early warning to Israel, and enhance the Patriot missile defense system by alerting battery units to impending attacks (10:4).

Mapping

Mapping is defined as the use of space systems to create topographic, hydrographic, and geological maps and charts and develop systems of topographic

measurement (28:37). This task is primarily performed by a U.S. civilian satellite system known as LANDSAT and a French satellite system called SPOT. Each system circles the earth repeatedly providing detailed images of the earth's surface eliminating the problem of outdated and misleading maps (11:52). When combined with GPS, the satellite information can be as good as any commercial map (12:54).

The final space function, force application is concerned with combat missions conducted from space against terrestrial targets. This function, when performed from space, would encompass traditional Air Force combat missions such as strategic offense and defense, interdiction of enemy forces, and close support of ground units (1:Sec 15, 12). The only current proposed capability in this area could occur through the Space Defense Initiative (SDI) for ballistic missile defense (33:10). While the development and deployment of weapons in space is still years, if not decades away, future space weapons are an inevitability and will revolutionize warfare (10:1).

Current Space Modeling Efforts

The functions and tasks presented in Figure 2-2 provide the criteria used in determining how space is currently being modeled in the more widely used theater level models. In this analysis, three questions will be asked of the model in regards to each space functional area.

1. Can the model simulate this function?
2. Are satellite dynamics modeled in regards to this task?
3. How does the model simulate this function?

The answer to the first question hinges on whether the impact of this task has an effect on the wargame. For example, if surveillance data affects how targets are attacked, then the model is said to play surveillance. To answer the second question, it must be known what, if any, objects or algorithms within the game are assigned with this task. Of primary concern are objects or algorithms that exhibit the characteristics of space systems. These characteristics include orbital mechanics of effects on the task by the environment. The answer to the final question will be a brief description of how the task is played and the impact of that task on the model.

The systems to be studied are the Joint Theater Level Simulation (JTLS), the Integrated Theater Engagement Model (ITEM), Tactical Warfare (TACWAR), JANUS, THUNDER, Extended Air Defense Simulation (EADSIM), and the Aggregate Level Simulation Protocol (ALSP) confederation of models. The first five listed fall into the campaign level of models while EADSIM is a mission level model. ALSP is not necessarily a model but a confederation of dissimilar models made to work together.

Checklist Summary

Explicit representation of space forces, specifically satellites, is lacking in the campaign level models. Also missing from these games are simulations of tasks other than those that fall under the umbrella of force enhancement. In regards to including space forces in the battle, the focus appears more to exploit, rather than to control space. None of the games model any of the functions of space support or space control while the only force application task modeled is ballistic missile defense. The engagement and destruction of terrestrial objects that represent a side's ground control network is possible

in all of the games. However, destruction of these objects would have no effect on the outcome of the scenario.

Force enhancement is the primary area where space effects influence wargame results. Most wargames model force enhancement functions implicitly through the scripting of effectiveness in probability of kill (P_k) tables. Scripted effects are those which have been set at the beginning of the game to happen at known times in the simulation. Examples of this would be setting up a GPS outage at a particular time to see how game players react. However, model users rarely take the time to script less than perfect performance of these functions. Therefore, the true nature of space forces is irrelevant to the model outcome. When there is explicit modeling of a particular space related task, the task is performed by terrestrial units. This explicit modeling could conceivably provide a means to infuse satellite characteristics into the game.

Joint Theater Level Simulation (JTLS)

JTLS is an Army computer-assisted, theater-independent wargaming system that models two-sided air, ground, and naval combat. JTLS can be used for warfare training, joint operational planning, and doctrinal analysis with an emphasis on rapid production of results (18:viii). The only space tasks JTLS models are communications and intelligence. Theater communications are slowed by distance and jamming. This delay in turn effects when units are assigned to accomplish particular tasks. Explicitly modeled human intelligence (HUMINT) teams provide the only intelligence within the game (1).

TABLE 2-1: CHECKLIST OF SPACE POWER IN THEATER LEVEL MODELS

	JTLS	ITEM	THUNDER	TACWAR
I. Functions A. Tasks	**1. CAN MODEL PLAY** **2. IS SPACE MODELED** **3. HOW MODEL PLAYS**	**1. CAN MODEL PLAY** **2. IS SPACE MODELED** **3. HOW MODEL PLAYS**	**1. CAN MODEL PLAY** **2. IS SPACE MODELED** **3. HOW MODEL PLAYS**	**1. CAN MODEL PLAY** **2. IS SPACE MODELED** **3. HOW MODEL PLAYS**
I. FORCE ENHANCEMENT				
A. Communications	1. Yes 2. No 3. Comm slowed by distance and jamming affecting when force elements are assigned to accomplish tasks	1. No 2. No 3. N/A	1. Yes 2. No 3. Intra-theater comm handled explicitly for IADS and ground forces; implicitly for ATOs and other military comm	1. Yes 2. No 3. Perfect connectivity assumed unless otherwise scripted
B. Navigation and Positioning	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. Yes 2. No 3. Effects of GPS played through SABSEL Pks for GPS weapons; User scripts GPS problems	1. Yes 2. No 3. Effects of GPS played through SABSEL Pks for GPS weapons; User scripts GPS problems
C. Intelligence and Surveillance	1. Yes 2. No 3. HUMINT teams provide target information affecting when, where and how targets are attacked	1. No 2. No 3. N/A	1. Yes 2. No 3. Intelligence functions and effects scripted; surveillance provided explicitly through JSTARS; Sat surveillance scripted in levels of enemy force disposition	1. Yes 2. No 3. Assumed perfect unless otherwise scripted
D. Environmental Monitoring	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. Yes 2. No 3. User inputs weather data to explicit weather stations; mission planned against forecasted weather and flown against realized weather	1. No 2. No 3. N/A
E. Warning	1. No 2. No 3. N/A	1. Yes 2. No 3. Early warning and Ground controlled intercept (EW/GCI) sites provide warning of attacks based on probability of detection	1. Yes 2. No 3. Impact captured in TBM effectiveness tables	1. No 2. No 3. N/A
F. Mapping	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A

TABLE 2-1: CHECKLIST OF SPACE POWER IN THEATER LEVEL MODELS

	JTLS	ITEM	THUNDER	TACWAR
I. Functions A. Tasks	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**
II. FORCE APPLICATION				
A. Ballistic Missile Defense	1. No 2. No 3. N/A	1. Yes 2. No 3. Terrestrial defenses engage incoming threats	1. Yes 2. No 3. Terrestrial defenses engage incoming threats	1. Yes 2. No 3. Explicitly defined TBM and active air defenses engage incoming threats
B. Power Projection	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Air, Land, Sea Defense	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
III. SPACE CONTROL				
A. Space Surveillance	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
B. Protection	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Negation	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
IV. SPACE SUPPORT				
A. Satellite Control	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
B. Logistics of System	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Spacelift	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A

TABLE 2-1: CHECKLIST OF SPACE POWER IN THEATER LEVEL MODELS

	JANUS	EADSIM	ALSP CONFEDERATION
I. Functions A. Tasks	1. CAN MODEL PLAY 2. IS SPACE MODELED 3. HOW MODEL PLAYS	1. CAN MODEL PLAY 2. IS SPACE MODELED 3. HOW MODEL PLAYS	1. CAN MODEL PLAY 2. IS SPACE MODELED 3. HOW MODEL PLAYS
I. FORCE ENHANCEMENT			
A. Communications	1. No 2. No 3. N/A	1. Yes 2. Yes 3. Models each message from generation to transmission and associated delays	1. No 2. No 3. N/A
B. Navigation and Positioning	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Intelligence and Surveillance	1. Yes 2. No 3. Sensors attached to ground units affect targeting and movement	1. Yes 2. Yes 3. Explicit satellites, aircraft and ground units provide surveillance and intelligence data to offensive and defensive units to engage threats	1. Yes 2. Yes 3. Explicitly provided by satellites and aircraft through the Tactical Simulation (TACSIM) and the National Wargaming System (NWARS)
D. Weather	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
E. Warning	1. No 2. No 3. N/A	1. Yes 2. Yes 3. Warning information provided to defensive, offensive and reconnaissance forces to engage threats	1. Yes 2. Yes 3. Explicitly provided by the Portable Space Model (PSM)
F. Mapping	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1, No 2. No 3. N/A

TABLE 2-1: CHECKLIST OF SPACE POWER IN THEATER LEVEL MODELS

	JANUS	EADSIM	ALSP CONFEDERATION
I. Functions A. Tasks	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**	**1. Can Model Play** **2. Is Space Modeled** **3. How Model Plays**
II. FORCE APPLICATION			
A. Ballistic Missile Defense	1. No 2. No 3. N/A	1. Yes 2. Yes 3. Ground, air, and space-based units target and engage threat missiles	1. Yes 2. No 3. Ground units from several models target and engage threat missiles
B. Power Projection	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Air, Land, Sea Defense	1. No 2. No 3. N/A	1. Yes 2. Yes 3. Space-based intelligence assets target and engage TBM launchers (TELs)	1. No 2. No 3. N/A
III. SPACE CONTROL			
A. Space Surveillance	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
B. Protection	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Negation	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
IV. SPACE SUPPORT			
A. Satellite Control	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
B. Logistics of System	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A
C. Spacelift	1. No 2. No 3. N/A	1. No 2. No 3. N/A	1. No 2. No 3. N/A

Integrated Theater Engagement Model (ITEM)

ITEM is a Navy model providing fully integrated air, land, and naval warfare engagement modules for the analysis of joint-force operations in theater level campaigns (26:Sec 1, 1). ITEM only simulates the force enhancement task of warning and the force application task of ballistic missile defense. Early Warning/ Ground Controlled Intercept (EW/GCI) sites provide missile warning information to the terrestrial ballistic missile defense assets that ITEM models. Detections are based on probabilities of detection and detection range while threat intercepts are based on missile versus missile P_k tables (26:Sec 7, 1-2).

THUNDER

Thunder is an Air Force model used in the joint arena to conduct analyses, ranging from the impact of individual weapon systems through total force structure composition. Thunder explicitly represents land, sea, and air forces, and includes all of the force enhancement functions except for mapping (3). Most notably, environmental monitoring is modeled extensively. Prior to a simulation run, the model user inputs forecasted weather data to explicitly represented ground stations. Mission planning uses on this forecasted data and the missions fly against the realized weather which affects target acquisition. Communications for the Integrated Air Defense System (IADS) and ground forces are modeled on a message by message basis to explicitly designated communication nodes. Air Tasking Orders (ATOs) and other military communications are modeled without the use of any assets. Each side uses surveillance data provided explicitly by JSTARS and AWACS and implicitly by satellites to execute battle plans.

The timeliness, quality, and quantity of the acquired data influences air-to-surface mission efficiency. Users script intelligence functions and effects, as well as the navigation and warning tasks. The user can also script the effects of GPS for guided munitions and any associated problems in the P_k tables. The one force application function modeled is ballistic missile defense (BMD) in which terrestrial defenses engage the threats. BMD performance is improved by the warning data scripted into the effectiveness tables (3).

Tactical Warfare (TACWAR)

TACWAR is an Army model used in the joint arena for Major Regional Conflict (MRC) force structure assessments and Operations Plan development. It simulates army and air force units (2). The only non-scripted space task modeled in TACWAR is ballistic missile defense which is done by terrestrial Tactical Ballistic Missile (TBM) defenses. Navigation is modeled through the P_k tables for guided munitions. As in Thunder, GPS problems can be scripted into the table. While not usually done, TACWAR users can script communication connectivity and intelligence less than perfect (2).

Janus

Janus is an Army ground combat simulation (31). The primary emphasis is land forces with limited air and naval operations. It is used for analysis, training and education (24). The only space related task modeled in Janus is intelligence and surveillance which is performed by sensors attached to ground units. These sensors affect unit movement

and targeting. Janus assumes all other space functions to be perfect unless the weapon effectiveness tables are adjusted (31).

Extended Air Defense Simulation (EADSIM)

EADSIM is an analytic model of air and missile warfare used in scenarios ranging from few-on-few to many-on-many. It models each platform, such as an aircraft and satellites, as well as the interactions among the platforms. EADSIM models the Command and Control (C2) decision processes and the communications among the platforms on a message-by-message basis. Intelligence gathering is explicitly modeled and the intelligence information used in both offensive and defensive operations (30:Sec 2, 1). Based on the mission EADSIM is designed to simulate, the modeling of space systems in support of that mission is essential. Satellites perform all the tasks affecting theater air defense, including communications, intelligence and surveillance, missile warning, and ballistic missile defense explicitly. Command, control, communications and intelligence (C3I) is the core process of EADSIM. C3I performs the communi-cations function by modeling the delays associated with host-to-communications device interface (29:Sec 4, 1). EADSIM models both an Intelligence Collection and Analysis Center (Intel CAC) and an Early Warning Data Processing Center (EWDPC) to correlate, fuse and process sensor data. The Intel CAC focuses on processing the surveillance data provided from varied collection sources and reporting this targeting information to various units. Tasks outside these are not simulated at any level. The EWDPC emulates the data processing capabilities of a Joint Tactical Ground Stations (JTAGS) used to perform the ground data processing of missile detection data

gathered by early warning sensors. Data passes from early warning sensors to the EWDPC for further dissemination. The primary user of this data is the surface-to-air ballistic missile defense systems (29:Sec 4, 9).

Aggregated Level Simulation Protocol (ALSP)

ALSP is a tool developed to respond to a desire to be able to reuse known reliable service models to train in a joint environment. ALSP allows disparate simulations to interact through a common, message-based protocol interface. Aggregate level simulations representing distinct segments of a battlefield, connected by the ALSP, provide a common environment to support major training exercises. An Army model, Corps Battle Simulation (CBS), represents army ground operations. The Air Warfare Simulation (AWSIM) provides detailed air operations and the Navy's Research, Evaluation, and Systems Analysis (RESA) represents naval force operations (14). Other models involved in this confederation are the Joint Electronic Combat Electronic Warfare Simulation (JECEWSI), the Tactical Simulation, and the Marine Tactical Warfare Simulation (MTWS). The Portable Space Model (PSM) explicitly portrays missile warning from a variety of assets including satellites. The Tactical Simulation (TACSIM) displays intelligence and surveillance gathering from satellites and air forces. Despite planning to incorporate simulations which model communications, navigational support, and weather into the confederation, decisions on which models to include have not been made (19).

Conclusion

The purpose of studying the wargames listed above is to determine if any of them satisfactorily models space in such a way that could be incorporated into an existing campaign level model. The modeling of space forces, especially in the campaign level models, is apparently lacking. None of the models take into account the dynamic nature of spacecraft and their missions. EADSIM's explicit representation of the tasks associated with theater air defense is impressive and could be potentially useful, but raises the question of how much detail is necessary if space is to be incorporated into a campaign level model. The ALSP construct introduces the idea of introducing the missing functions through the use of a model designed to perform those functions. While conceivable, this solution is a difficult one to implement due to the requirement of a common simulation protocol that would allow the differing models to communicate. Also, the mission level models that would have to be used to provide space to a theater level model tend to be very data and labor intensive. This fact may inhibit the use of some larger model by extending the preprocessing time. These results suggest that the construction of a methodology for incorporating into theater level models will have to come from somewhere besides the models analyzed in this chapter. A study of how actual space forces operate and how they are modeled in mission level space simulations will be the next avenue of exploration to address this problem.

III. Methodology

Introduction

As seen in the first two chapters, space forces play a vital role in the conduct of real world conflicts while at the same time being virtually ignored in campaign level models. Chapter II points out the lack of adequate space representation in the current suite of widely used theater models. In these models, space is treated as a mission[1] rather than a place where a variety of missions are performed. In this manner, the space mission has little impact on the terrestrial battlefield. The dynamic nature of the space environment and the tasks[2] performed in space must be incorporated in theater level models to better represent space's influence on the actions of military forces. When support to warfighters is mentioned, a distinction must be made as to who exactly the warfighter is. Decision makers act on all levels of war--strategic, operational, and tactical--and therefore utilize all the functions[3] space provides to plan future actions. However, the forces engaged in carrying out those plans are primarily serviced by navigation and positioning data. Navigation and positioning satellites help to complete missions and put bombs on target.

To this end, the tasks performed by the U.S. military in space will be studied individually in an attempt to define how space functions can be best incorporated into campaign level models. The essence of these models will be to explicitly represent the

[1] Missions describe broad military objectives attained by employing forces.

[2] Tasks are the force capabilities which fall under each function.

[3] Functions are specific areas of operations.

effects space has on the battlefield with implicitly modeled satellites. There is no attempt to directly model all the properties of satellites but to provide a vehicle for the attributes of space forces to be incorporated into models. One of the most important issues to consider is the availability of satellite information. Low earth orbiting satellites pass over certain areas of the globe a limited number of times a day. Therefore, information from these systems may not be as timely as desired. This chapter will include flowcharts for each space task that will illustrate methods for implementing space in any theater model. Each flowchart includes the symbols defined in Appendix A.

Navigation and Positioning

As demonstrated by U.S. efforts in Desert Storm, the Global Positioning System (GPS) has a remarkable effect on the ability of weapon systems to put bombs on targets. In practice, GPS is very heavily intertwined with every aspect of combat. Therefore, the representation of the GPS system within a model will have a much broader reach than the modeling of any other space function. Because the GPS system is unclassified, a GPS model can accurately calculate an depict exact locations.

The 1994 Rand publication titled "Modeling Global Positioning System Effects in the TLC/NLC Model" provides a methodology of incorporating contributions of the GPS in a theater level model (7). This model was designed to represent the effects of GPS in support of military campaigns. The TLC/NLC model is a theater-level nonlinear combat model used at RAND to support policy-level analysis of military operations. The model design represents the aggregate effects provided by GPS support (7:xii). GPS

transmissions will increase average movement rate for ground units, increase lethality against targets, allow additional platforms to provide target designations and reduce vulnerability to enemy air threats and flight times through stand-off munitions launch. The process of incorporating GPS effects in a model will be taken exactly from the Rand publication (7:22-28).

With this level of aggregation, modeling the explicit GPS constellation over time or its exact location is unnecessary. Only approximate values for location accuracy consistent with the location accuracy available in the model are required (7:xii). The model sequence Rand uses to display GPS effects is modified and shown in Figure 3-1 (7: 18). A departure from Rand's approach considers possible jamming effects on GPS receivers before the model calculates any values.

The three types of GPS coverage are absolute, differential, and relative targeting. Absolute GPS coverage comes in two forms of access: military (also called precise positioning service or PPS) and civilian (also called standard positioning service, SPS). Military access provides the best accuracy to determine a platform's velocity and location in four dimensions (latitude, longitude, elevation, and time). As long as the platform with a GPS receiver has line-of-sight access to four or more GPS satellites in a favorable geometry, the receiver will be able to determine its three-dimensional (3-D) location to about 10-16 meters Spheroidal Area Probable (SEP). Given the current orbital configuration of the full GPS constellation, most of the earth's surface has line-of-

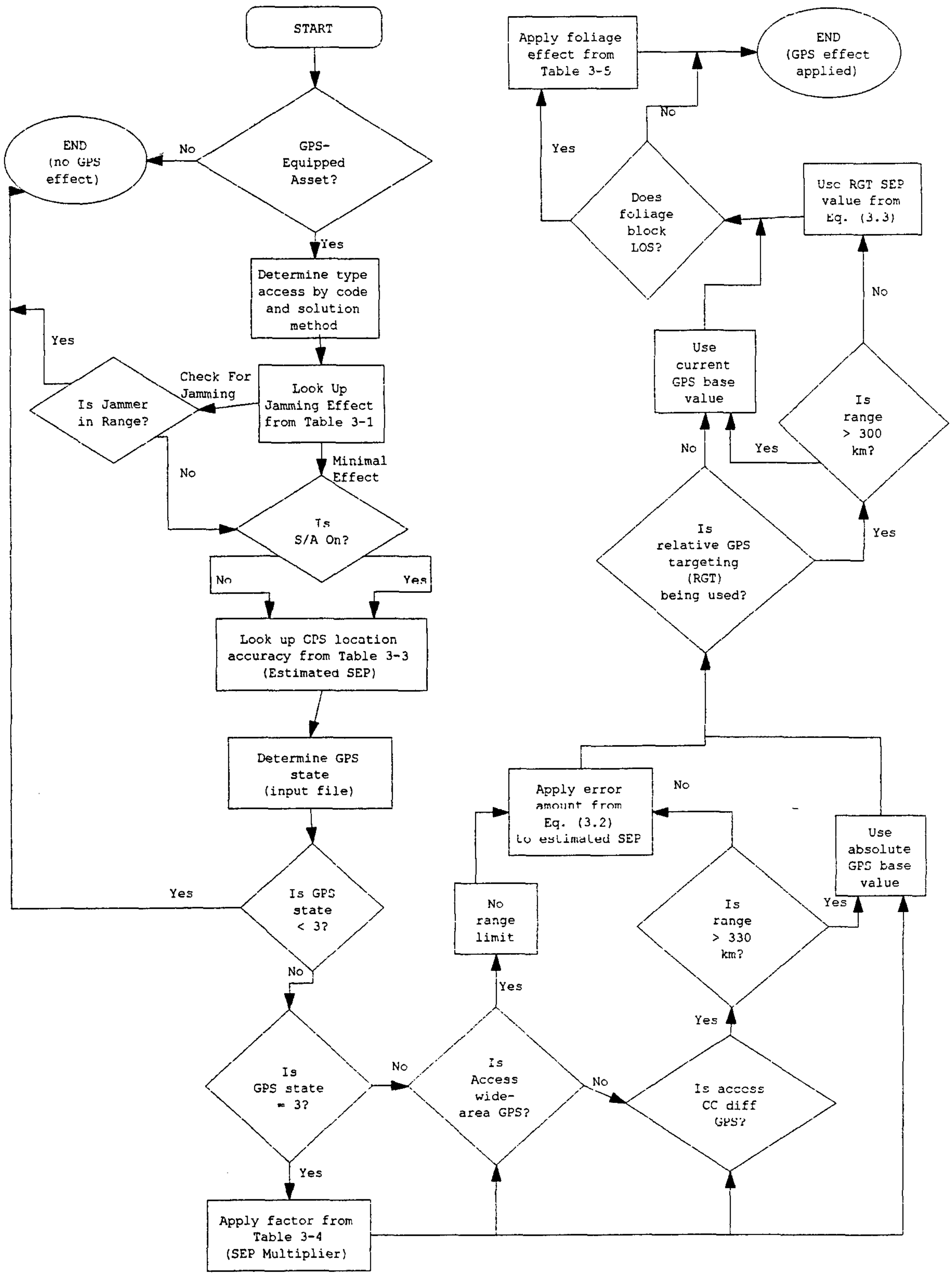

Figure 3-1: Navigation and Positioning Process

ight to four, five, or even six satellites at any given time. A given set of four GPS atellites accessed by a specified ground receiver will have an area of overlap on the round of about 1000 km on a side. This area of overlap can be considered to cover the ntire area of interest (AOI) and will be represented by a variable called "GPS state." he GPS state represents the number of GPS satellites expected to be over the theater in ıvorable geometry at a given moment. Because the exact GPS constellation is not ıodeled, off-line analysis of the actual GPS constellation can be done to determine the PS state over time. A software package, such as the System Effectiveness Model EM) used by Air Force Space Support Teams, can predict the number of satellites over e (AOI) during the time to be studied (7:6-9). The GPS state that applies across the eater at any given time can be stored as a sequence of numbers, only one of which plies at a given time for the model run. An additional binary variable will also be eated to define whether selective availability (S/A) is "on" or "off." This variable will fect the transmission accuracy for Civilian Access (C/A) code users (7:xiii).

The flowchart in Figure 3-1 begins by inquiring whether the platform or munition GPS-equipped. If not GPS-equipped, the platform does not receive any GPS benefit. the asset is GPS-equipped, then the type of access must be determined. The type of cess to the GPS signal is broken into the following categories (7:16-17).

None

Civilian Access (C/A) code, no differential access

P-code, no differential access

- Civilian Access (C/A) code, coordinate correction differential access
- P-code, coordinate correction differential access
- Civilian Access (C/A), wide-area access
- P-code, wide-area access

P-code access is the most accurate GPS transmissions and reserved for military and other authorized users. The Department of Defense can degrade the transmission of the GPS signal to civilian users by turning S/A on. Civilian access (C/A) to GPS transmissions are less accurate than military access by roughly a factor of two when S/A is off. If S/A is turned on, civilian access signals are further degraded by about a factor of five (7:7).

Differential GPS coverage, or differential access, is broken down into coordinate correction and pseudo-range correction. Both coverage types provide location error correction data to GPS receivers. The most common and least expensive form of coordinate correction differential GPS is provided by an additional GPS transmitter stationed at a known location, usually on the earth's surface. This additional transmitter site collects GPS satellite transmissions over time, compares the location observations in these transmissions with its own location, and sends the coordinate correction data to GPS receivers that are within transmission or relay range. As long as the location of this transmitter is known to a high degree of accuracy, the P-code accuracy of the user receivers is improved to about 2-4 meters SEP which is about one-fifth that of regular P-code transmissions. The differential GPS location accuracy C/A code is 4-8 meters

rather than 20-30 meters without the correction code. The correction code eliminates the selective availability error to C/A code users. Thus, using coordinate correction, a civilian C/A user can achieve better SEP than a military user accessing absolute P-code transmissions. This advantage is a function of the distance to the differential GPS transmitter. The farther the transmitter, the less accurate is the location accuracy of the receiver. As a rule of thumb, SEP increases one meter for every 80 km of distance to the transmitter up to 320 km. Somewhere between the 300 and 350 km range, the coordinate correction differential GPS transmitter and the receiving platform will not share the same four satellites, rendering coordinate correction differential GPS unusable. The transmission distance can be increased with the use of relay stations to broadcast the coordinate correction to more receivers. However, location accuracy is still based on the receiver's distance from the fixed transmitter and not based on the location of the relay stations. This process requires line-of-sight between the GPS receiver, relay stations, and the transmitter (7:9-10).

Pseudo-Range correction or wide-area differential GPS access is similar to coordinate correction without the range limitations. These limitations are avoided by a transmitter of known location transmitting correction factors to all the satellites in the constellation when they are observed. The improvement in GPS accuracy is the same as the coordinate correction differential (7:11).

After the type of GPS access is determined, a check is made for possible jamming threats against these GPS assets. While another threat against GPS assets consists of direct destruction of GPS receivers and transmitters, direct threats to transmitters can be

modeled like any other asset within the model. Given that GPS receivers tend to be contained in an asset, destroying the GPS receiver tends to destroy the platform as well. Therefore, there need not be any special coding done to model GPS receiver destruction. Jamming is the most effective and most likely threat against GPS signals, so jamming assets should be modeled. Jammers can be represented as separate objects or as attributes of a target. Distinctions will be made between narrow-band and wide-band jammers as well as ground-based and airborne jammers. Each of these jammer types is more or less effective against nulling software and directional antenna counter-countermeasures. The resulting decrease in location accuracy will be translated into decreased lethality or decreased probability of reaching the target. Counter-countermeasures could be added as possible attributes to the GPS assets that are assigned to various platforms (7:33). Table 3-1 shows jammer effects on an absolute GPS receiver, an absolute GPS receiver with nulling software and an absolute GPS receiver

Table 3-1

Determination of Possible Jamming Effects

Type of Jammer	Type of Absolute Receiver Addition	Effect of Jamming	Power Factor
Narrow-band ground	None	Check for jamming	1.0
Narrow-band ground	Nulling Software	Minimal Effect	1.0
Narrow-band ground	Both	Minimal Effect	0.033
Narrow -band air	None	Check for jamming	1.0
Narrow -band air	Nulling Software	Minimal Effect	1.0
Narrow -band air	Both	Minimal Effect	1.0
Wide-band ground	None	Check for jamming	1.0
Wide-band ground	Nulling Software	Minimal Effect	1.0
Wide-band ground	Both	Minimal Effect	0.033
Wide-band air	None	Check for jamming	1.0
Wide-band air	Nulling Software	Minimal Effect	1.0
Wide-band air	Both	Minimal Effect	1.0

with both nulling software and a directional antenna. These receivers can be either air or ground based (7:34).

If "Effect of jamming" is "Minimal effect," then normal target location accuracy calculations occur unless the jammer power is very large. Very large in this case would be classified as a power over 100 watts. If the Table 3-1 indicates "Check for jamming," then Table 3-2 determines the approximate range at which jamming takes place (7:34).

Table 3-2

Determination of Range of Jamming to Break Lock or Preclude Signal Acquisition

(A = Aircraft, G = Ground)

Type Jammer to Type Receiver	Type User or Access	Jammer Power (W)	Range (km) at Which Jamming Breaks Lock	Range (km) to Preclude Signal Acquisition
A-A, A-G, G-A	P-code	1	4.5	43
A-A, A-G, G-A	P-code	10	13.5	135
A-A, A-G, G-A	P-code	100	43	427
A-A, A-G, G-A	C/A code	1	13.5	120
A-A, A-G, G-A	C/A code	10	43	380
A-A, A-G, G-A	C/A code	100	135	1200

Table 3-2 determines the estimated range that a jammer with the indicated effective radiated power could break a GPS receiver's lock on an already acquired GPS signal. This table also includes the range at which the GPS signal will not be acquired by a receiver as a function of the jammer power. If the GPS receiver is within range of the jammer, then no GPS effect is applied and the module ends. Otherwise, calculation of the effect continues as prescribed by Figure 3-1 (7:34).

If the jammer is ground-based and the receiver airborne, the jammer's power

must be multiplied by the power factor in Table 3-1. This factor accounts for the fact that a ground-based jammer attempting to jam a directional antenna will require about 30 times as much power as an airborne jammer to achieve the same effect. The jammer power decreases roughly as the inverse square of the range due to minimal reflections, or

$$\text{received power} = \text{power factor} * \text{jammer power}/(\text{range})^2 \tag{3.1}$$

Note that these numbers apply to jammers within line-of-sight of receivers. In the case of ground-based jammer against a ground-based receiver, additional attenuation causes the jammer power to decrease more quickly as a function of range after the first kilometer. Depending on environmental conditions, the decrease in power may be as much as the third or fourth power of the range. As a result, ground-based jammers tend to be relatively effective against P-code receivers within 1 km of the jammer (7:35).

Jamming against air and naval platforms will be treated as attempts to break the signal lock of GPS receivers and will be determined by the fourth column of Table 3-2. Because units in foliage are unlikely to be able to maintain a continuous lock on the GPS signal, jamming against ground units will be determined using the last column of Table 3-2. This means ground units in heavy foliage will more susceptible to enemy jamming. All friendly units within one kilometer of enemy GPS jammers are considered unable to maintain lock on the GPS signal (7:34).

One of the best counter-countermeasures to jamming of GPS signals is to attack the jammers. Since jammers must radiate nearly continuously at sufficient power to jam at long range, they are detectable targets and can be attacked like other targets within the model (7:34).

Once the possibility of jamming is negated, Figure 3-1 asks whether selective availability is on. If so, then any non-U.S. military absolute GPS access is further degraded. The base value for accuracy comes from Table 3-3, assuming a GPS state of greater than or equal to four. The type of access of the receiver, S/A state, and the solution method determine an initial value for the SEP. This value will be adjusted throughout the positioning process until the final GPS effect is calculated (7:19).

Table 3-3

Estimate SEP (meters) based on Access, S/A, and Solution Method

GPS State	Selective Availability (S/A)	Absolute GPS P-Code	Absolute GPS C/A Code	Differential GPS P-Code	Differential GPS C/A Code
>= 4	Off	10-16	20-30	2-4	4-8
>= 4	On	10-16	54-76	2-4	4-8

Figure 3-1 then leads us to examine "What is the GPS state?" If GPS state is greater than or equal to four, then GPS-equipped assets may receive full benefit from absolute GPS transmissions. If not, then all of the derived GPS benefits (wide-area differential, coordinate correction differential, or relative GPS targeting) are reduced during this assessment cycle, as shown in Table 3-4 (7:19). Note that GPS state is the basis of all subsequent calculations. All location accuracies derive from on the base location accuracy provided by the GPS state. This initial SEP value is then affected by whether or not some type of differential access is being used. If wide-area differential GPS is being used, there is no maximum range limitation, but there is a range

Table 3-4

Approximate SEP Multiplier As A Function Of GPS State

GPS State	SEP Multiplier with INS	SEP Multiplier without INS
Favorable (>= 4)	1.0	1.0
Reduced (= 3)	1.0	2.0
Poor (< 3)	No GPS effect	No GPS effect

degradation effect. The decrease in location accuracy is about 1 meter SEP for every 80 km and is displayed in Equation 3.2 (7:19-20).

$$\text{New SEP} = \text{Initial SEP} + (1\text{ m} * (\text{range to transmitter}/80\text{ km})) \tag{3.2}$$

If coordinate correction differential GPS is being used, there is a maximum range limitation of about 300-350 km as explained earlier. Similar to wide-area differential, location accuracy will degrade with distance in accordance with equation 3.2 (7:19-20).

After the new SEP is calculated, the flowchart seeks to know whether the platform, sensor, and munitions combination accommodates relative GPS targeting. Relative GPS is a method by which munitions can be more accurately guided to their targets. Target locations are measured relative to a GPS-equipped platform, and that platform's apparent GPS location is known with respect to the target. Similar to coordinate correction differential GPS, both platform and munition must be GPS-equipped and share the same satellites. Because of this, relative GPS targeting is limited to the minimum of about a 300-350 km range or a 10-15 minute flight time. The resulting munition accuracy is approximately 5-8 meter SEP for a P-code GPS-equipped platform and munition combination. This is more accurate than absolute GPS targeting, but less accurate than coordinate correction differential. If the target is beyond the 300-

350 km maximum range limitation or the munition's flight time is greater than 15 minutes, then relative GPS targeting cannot be used. Instead, the currently calculated GPS location accuracy is used. If the target is less than 300 km from the platform or the munition flight time is less than 15 minutes, a new SEP is calculated as shown in equation 3.3.

$$\text{RGT SEP} = 0.5 * \text{current GPS base value} \tag{3.3}$$

where RGT stands for relative GPS targeting, and the current GPS base value is a function of GPS state, as shown in Tables 3-3 and 3-4 (7:12-14,20).

Before the GPS effect is applied, a final determination is made as to whether foliage blocks line-of-sight from the receiver to the satellites. The GPS signal attenuates rapidly in foliage, so if foliage blocks line-of-sight between the GPS receiver and the satellites, the receiver will not be able to obtain or retain lock on the GPS signal. This problem primarily affects the movement rates of mobile ground units. The degradation can be represented in accordance with Table 3-5 (7:21). Note that these are not

Table 3-5

Effect of Foliage on Ground Asset Benefits

Type of Terrain	Multiplier of Increase in Unit Speed	Multiplier of Reduction in Congestion Rate
Clear	1.0	1.0
Forested	0.67	0.67
Jungle	0.33	0.33

multipliers of the unit's overall speed or congestion rate but rather multipliers of the increase and reduction in each as a result of continuous or instantaneous GPS access

(7:21). When this final assessment is made, the GPS effect can be applied to the actions of the platform.

Missile Warning/Ballistic Missile Defense

Defending friendly territory from tactical ballistic missiles requires both missile warning and defense, which is why these two space functions have been merged. Because ballistic missile defense from space has yet to become a reality, this function may not be applicable when implementing space functions into models. Figure 3-2 describes the process flow for these two functions and is based on the approach described by Hartman (16). Modeled in this way, missile warning satellites mimic the continuous looking model which is used by many high resolution combat simulations (16: Sec 4, 12).

The continuous looking model is based on a detection rate function D(t), which has the property of detecting a target in a short time interval is proportional to the length, DELTA-T, of the interval and is given by:

$$\text{Prob(detect in [t, t+DELTA\_T])} = D(t) * \text{DELTA\_T} \tag{3.4}$$

For missile warning satellites in this case, the assumption is D(t) = D = constant for all t.

In a longer time interval of length T = N * DELTA_T, equation 3.4 yields:

$$\text{Prob(detect in length T)} = 1 - (1 - D * \text{DELTA\_T})^N$$

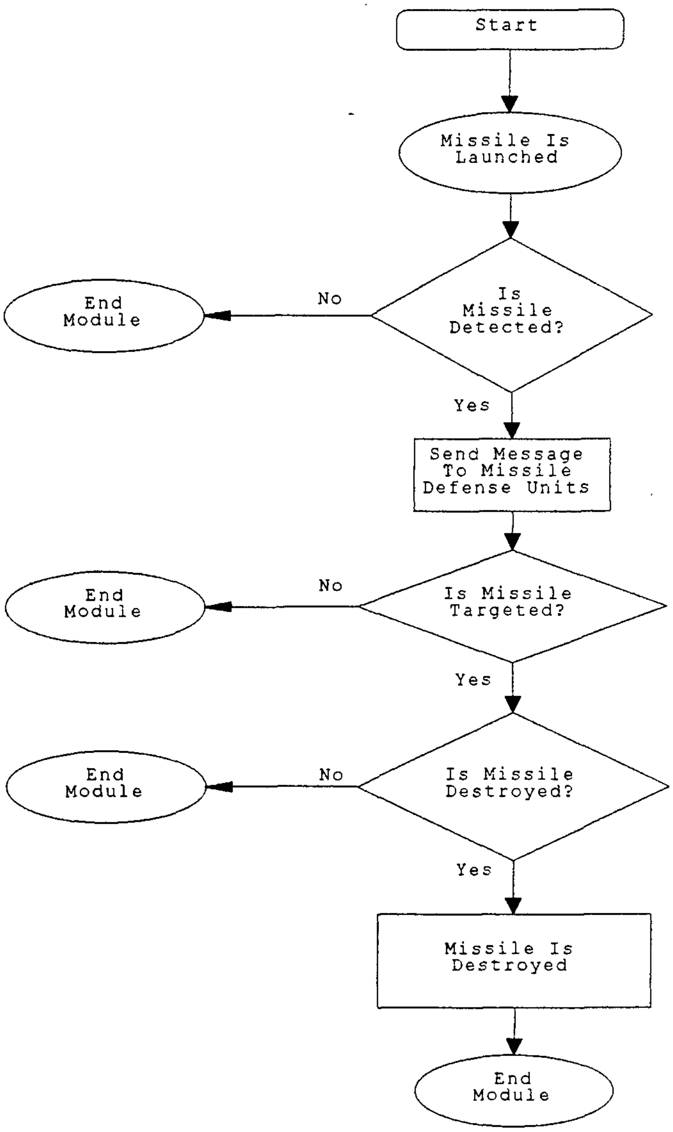

Figure 3-2: Missile Warning/Ballistic Missile Defense Process

$$\text{Prob(detect in length T)} = 1 - (1 - D * T/N)^N \qquad (3.5)$$

In the limit as N approaches infinity and DELTA_T approaches zero, with the product

T = N * DELTA_T held constant, equation 3.5 is equivalent to:

$$\text{Prob(Detect in length T)} = 1 - \exp(-D * T) \qquad (3.6)$$

Equation 3.6 is the cumulative distribution function (CDF) of the exponential distribution, the distribution most frequently used to model the time required to detect a

target (16:Sec 4, 12). Note that these functions comprise a reactionary process. The system takes no action unless a missile event has occurred. The process begins by using equation 3.6 to determine whether or not the missile is detected by the missile warning satellite. The warning satellite, which is in a geostationary orbit above the AOI, has a detection probability, D, for each type of theater ballistic missile (TBM). Because of the timing required to detect and defend against TBMs, the time T for detection is limited to a few minutes. Detection is based on a random draw against the computed probability of detection. If the missile is not detected, the module ends. If the missile is detected, a message is generated and sent to land and space missile defense units, including those units assigned the task of engaging the missile launchers.

The missile defense satellite then attempts to detect and target the missile. The model assumes this satellite is in a geostationary orbit near the position of the missile warning satellite. Once the missile defense satellite receives the launch warning, another random draw against a second probability of detection determines if this satellite detects and targets the missile. The defending satellite only gets one chance to target and destroy the missile. If the missile is not targeted, the module ends. If the missile is targeted, the satellite attempts to hit and destroy the target. The probability of the satellite hitting and killing a particular missile is combined for ease of computation. A random draw is taken against this probability of hit and kill to determine if the missile is destroyed. Whether or not the missile is destroyed, the module ends and control returns to the main program.

Power Projection/Air Land Sea Defense

Attacking and defending terrestrial assets from space has yet to become a reality but is a relatively easy function to model. The major assumption made is that satellites assigned this function are in low earth orbit, and thus not available at all times. Off-line analysis of the desired orbit will provide the times and durations the satellite will appear over the AOI. These data can be loaded into the model database as overhead event times when the satellite is capable of engaging a target. Figure 3-3 displays the process flow for this function.

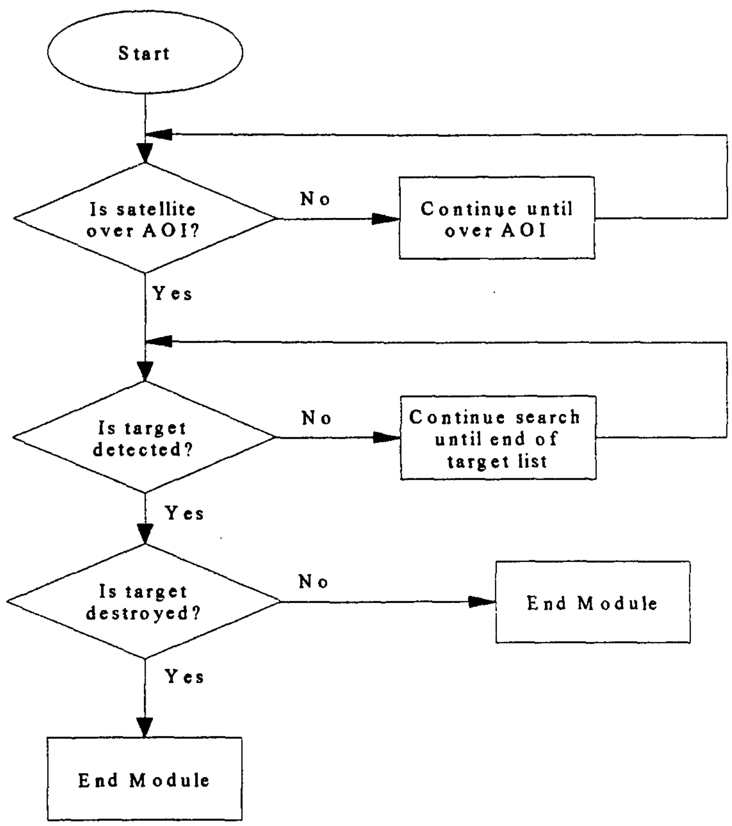

Figure 3-3: Power Projection/Air, Land, Sea Defense Process

Unlike the missile warning process which assumes a continuous looking model,

the this process supposes a glimpse model. A glimpse model is one in which an observer has intermittent chances to detect a target where a glimpse is denoted by each detection opportunity (16:Sec 4,5). For satellites, a glimpse is each time the satellite is over the AOI. By allowing g(i) to equal the probability of detection of the target on the ith glimpse assuming the search failed to detect the target on the previous i-1 glimpses and the target is present. Each glimpse is considered a Bernoulli trial with probability of success g(i). If g(i) = g for all i, and n equals the number of glimpses then (16:Sec 4,6-7):

$$\text{Prob(No detect on first n-1 glimpses)} = (1 - g)^{n-1} \qquad (3.7)$$

$$\text{Prob(First detect on the nth glimpse)} = g * (1 - g)^{n-1} \qquad (3.8)$$

$$\text{Prob(Detect in first n glimpses)} = 1 - (1 - g)^{n} \qquad (3.9)$$

For the purposes of this process, equation 3.9 is used to determine the probability that the satellite detects a target within the first n glimpses. When a satellite is assigned a target, the number of passes is recorded to determine the probability of detection.

The first step in the process is deciding whether the satellite is over the AOI. If not, the model will have to wait for the overhead event time before any target engagement occurs. If the overhead event time has arrived, a random draw determines target detection. Specific targets can be assigned to the satellite object prior to each overhead event or a target list given that would be engaged at each pass over the AOI. Each individual target has a probability of detection, g. If the target is not detected and there are other targets on the list, the satellite continues the search until the overhead event time has ceased. If there are no other targets on the list, the satellite waits until its

next pass.

After a target is detected, another random draw occurs to see if the satellite destroys the target. Again, probabilities of hit and kill are combined and assigned based on the type of target. The satellite has only one opportunity to destroy a target, and the module ends until the next overhead event if a shot is fired.

Intelligence and Surveillance

A wide array of space-based sensor systems are represented to include electronics intelligence (ELINT), communications intelligence (COMINT), image intelligence (IMINT), and infrared intelligence (IR). Each object in the model has a specific detection vulnerability to one or more of each type of intelligence gathering sensor. In a like manner, each type of intelligence sensor has specific types of targets that it can sense. Similar to the satellites modeled to perform power projection, the intelligence satellites are assumed to be low earth orbiting. Therefore, each sensor will only be able to detect targets at certain time intervals. Again, off-line analysis will determine each satellite's detection opportunity and the glimpse model's equation 3.9 will determine the probability of a satellite detecting a target. The intelligence collection process flow is displayed in Figure 3-4.

Before any target can be detected, the satellite must be over the AOI. This fact is assumed for the module to begin. Once the satellite is within this detection opportunity window, a random draw is taken against each object type within the field of view for the duration of the overhead event to determine which targets are detected. Information on the detected objects then goes to an information fusion center which updates the

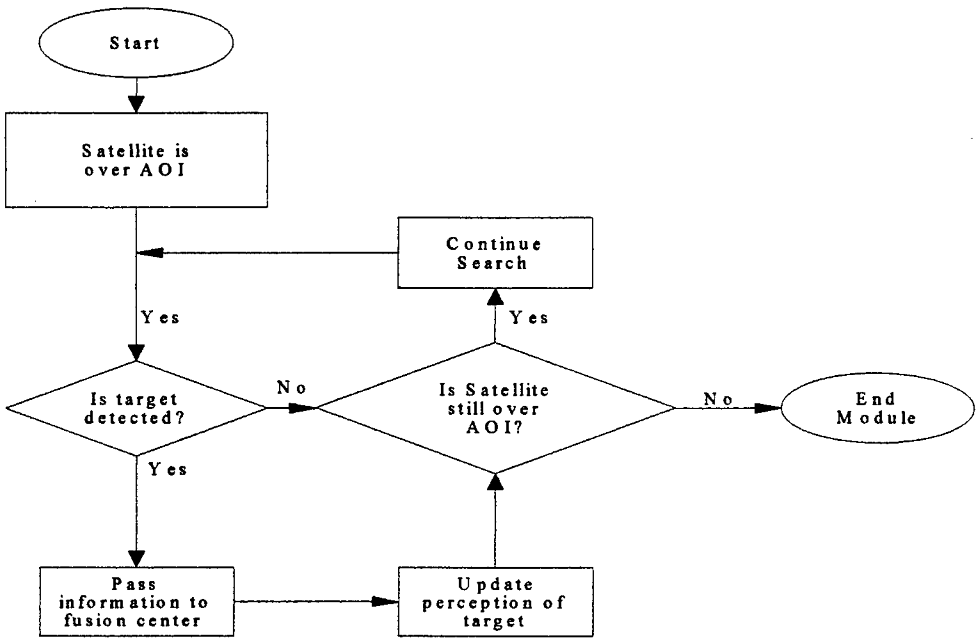

Figure 3-4: Intelligence and Surveillance Process

perception of that unit and makes it available to all friendly units. IMINT sensors cannot detect targets in poor weather or darkness and have no probability of detection during those times.

Weather

Weather data can come from a variety of sources but the most valuable weather information comes from satellites like the Defense Meteorological Support Program (DMSP) constellation. Weather data from these satellites are of prime importance in the planning and execution of missions. These satellites circle the earth in a sun-synchronous orbit, which means they pass over the same points on the earth at the same times everyday. Thus, detailed weather data are available each day for mission planning. The GRC Weather Utility Model as shown in Figure 3-5 demonstrates how weather

forecasts over the target area can be used to select weapon loads (17).

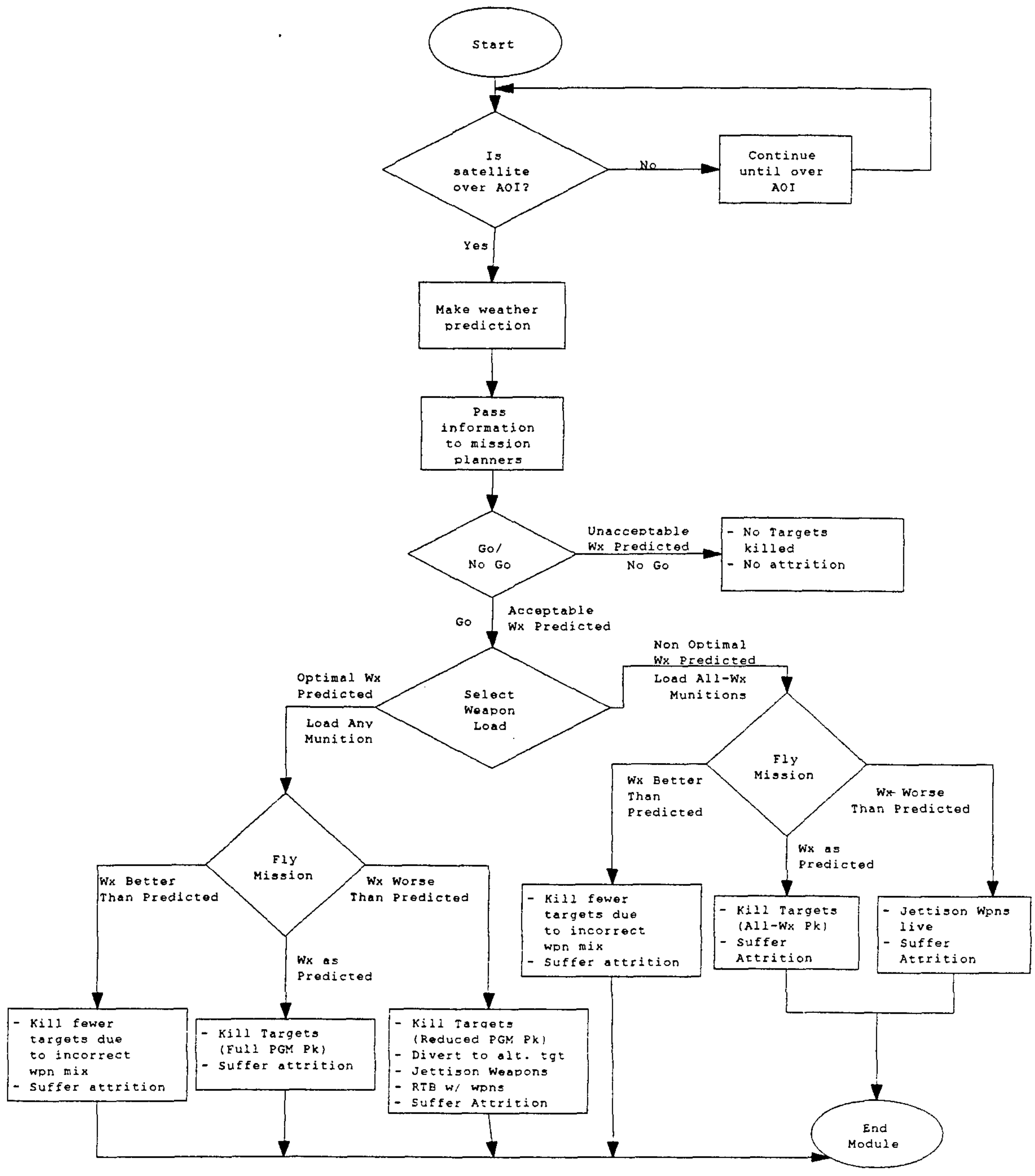

Figure 3-5: Weather Prediction Process

A Go/No Go decision is the first to be made after a weather prediction is forwarded. If unacceptable weather is predicted over the target area, then the mission is retasked until good weather, resulting in no killed targets and no friendly attrition. If

acceptable weather is predicted, the model selects a weapons load. Because rain and clouds inhibit the use of some types of Precision Guided Munitions such as Laser Guided Bombs (LGBs) and Electro-Optitcal Bombs (EOBs), GPS guided munitions or gravity bombs are the weapons of choice if inclement weather is forecast. Note that GPS weapons have the advantage of being all weather capable and work in either situation. However, LGBs and EOBs have a smaller SEP than some types of GPS PGMs and are preferred in certain situations (21). If weather is not a factor, any type of munition, ideally PGMs, are loaded onto the attacking aircraft. Missions then fly against the actual weather over the target.

If the weather is better than predicted, fewer targets would be destroyed due to an incorrect weapons mix loaded onto the aircraft. This is the result of weapons with lower probability of kill (P_k) being selected when higher P_k weapons could have been used. If the actual weather occurs as predicted, the weapons mix destroys targets at maximum efficiency due to correct weapons selection. If the weather is worse than forecasted and laser or electro-optical PGMs are used, fewer targets are killed because more weapons are needed to destroy the same number of targets. Missions would also have to divert to alternate targets, or some munitions jettisoned or brought back to base. The P_ks for these type of PGMs are greatly reduced in inclement weather because they are guided optically. The worse than forecasted weather forces non-PGM loads to be jettisoned resulting in no target kills. In all cases, aircraft suffer attrition with more losses occurring when aircraft are forced to divert. As the final steps in the weather process as defined in Figure 3-5 move to the right, the weather theoretically worsens forcing the cancellation of some missions.

Communications

As earlier stated, satellites carried nearly 85% of communications during the Gulf War. This fact alone demonstrates the importance of space-based communications in theater operations. Theater communications can be divided into three distance ranges, short, intermediate, and long range. Figure 3-6 shows communications on three typical networks that satisfy the distance requirements. These networks are defined as line-of-sight (LOS), troposcatter, and satellite/high frequency (HF). The effects of these communications networks on the theater will be represented by transmission delays and failures, generation of detectable emissions, and susceptibility to degradation.

Prior to implementation of this module, units are assigned to each type of network. LOS communications are short range messages occurring between combat units. These links simulate communications that propagate through the air without the aid of satellites. Messages traveling over troposcatter links flow from mobile ground units over distances up to 200 km. Satellite/HF communications have the longest range and cover the theater. Satellites represent the most reliable mode of communicating, especially in the dissemination of broadcast messages. Units use HF links to supplement satellite communications in the transmission of long range messages. These messages tend to be point-to-point and the network is less reliable than satellites. Each network is assigned transmission times, processing delay times, and network delay times based on a triangular distribution. A triangular distribution is one where each variable is assigned a

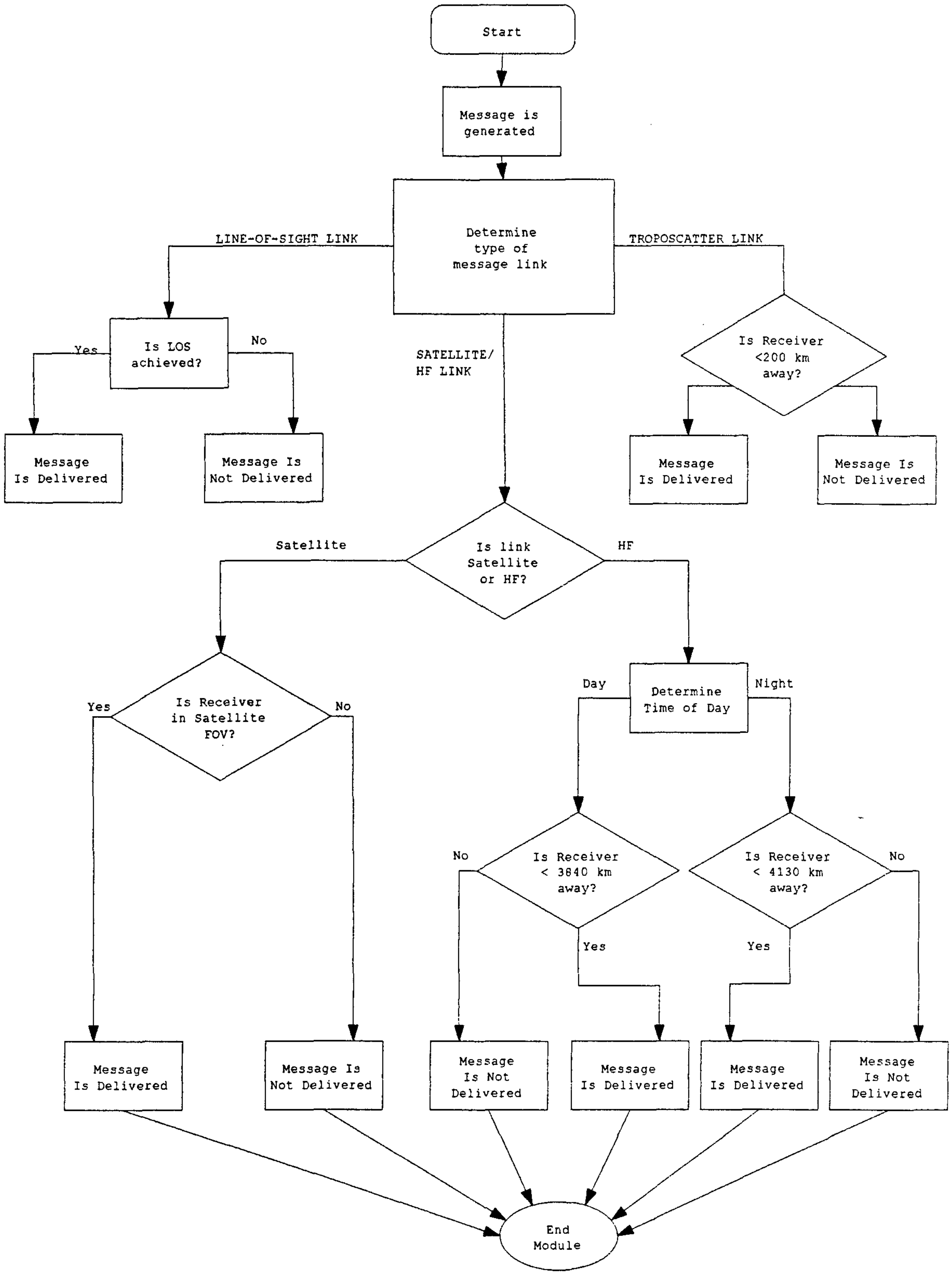

Figure 3-6: Communications Process

low, high, and mean value describing the range of values that variable can attain (20:341-342). The transmission times represent the range of times it takes to for a sender to code and transmit. The processing delay times are the range of times it takes for a receiver to process and distribute the message. The network delay is the time it takes for a message to travel between nodes. The receipt time for a message is calculated in the following algorithm:

Generate Random $U_i \sim$ Uniform (0,1) where i = 1,2,3

If $m_i \leq U_i \leq n_i$, return $X_i = (\sqrt{n_i * U_i}\ ) * c_i$

If $U_i > n_i$, return $X_i = (1 - \sqrt{(1 - n_i) * (1 - U_i)}\ ) * c_i$

Otherwise, choose new X_i

$$\text{Receipt Time} = \text{Current Time} + X_1 + X_2 + X_3 \tag{3.10}$$

Where:

X_1 = Transmission Time

X_2 = Processing Delay

X_3 = Network Delay

a_i = low value, b_i = high value, c_i = mean value

$m_i = \frac{a_i}{b_i}$ = scaled lower value

$n_i = \frac{c_i}{b_i}$ = scaled mean value

Once a message is generated, a decision must be made as to what type of message it is. Depending on the message, a series of checks determine if the message reaches its destination. The assumption is made that the receiving unit is alive. The requirement for an LOS message to be delivered is whether or not the communicating units have line-of-sight of each other. If so, the message is delivered after the associated delays. If not, the message is not delivered and is held to be transmitted at a later time. Once the delays are

calculated, the message is received at the receipt time as calculated in equation 3.10. A message transmitted over a tropospheric link requires the sender and the receiver to be within a 200 km radius of each other. If this condition is met, the message is delivered at the receipt time calculated in equation 3.10. Long range messages can be transmitted over satellite or HF links. If satellite links are used, there is no distance restriction and the message is delivered. HF links suffer from a distance limit based on the time of day. If the message is transmitted in the daytime, the sender and receiver must be with 3840 km. At night, the distance limit increases to 4130 km. Unless one of these conditions is met, the message is not delivered.

Each time a message is sent, the transmitter will create a detectable emission event. This event will extend for the duration of the transmission time and can be detected by enemy electronics intelligence units. Detectable emissions can be an important consideration for commanders trying to protect hidden forces.

Space Surveillance/Protection/Negation

Because these three tasks which make up the Space Control function are so closely intertwined, they will be discussed together. A satellite system contains three segments that can be attacked or defended. These segments are the space segment, the ground segment, and the command and control (C^2) segment (15:72). The space segment is represented by the satellite while the ground segment is composed of the receivers that collect the data from space. The final segment consists of the links connecting the first segments. It is on these segments that the tasks of protection and negation will be performed.

The space surveillance task provides information on all the satellites in orbit and supports the other two tasks by forwarding targeting information against the enemy's space segment. The U.S. worldwide space surveillance network tracks all the satellites in orbit. Because this network is beyond the control of theater commanders, this network is not explicitly modeled. Model users receive implicitly gathered surveillance information in the form of periodic orbital status reports with the overflight times of all satellites included. Overflight times of enemy intelligence satellites allow movements of friendly units without detection.

Targeting a satellite requires identification and continuous tracking (25:28). This process is diagrammed in Figure 3-7. The modeled system is collocated with the ground

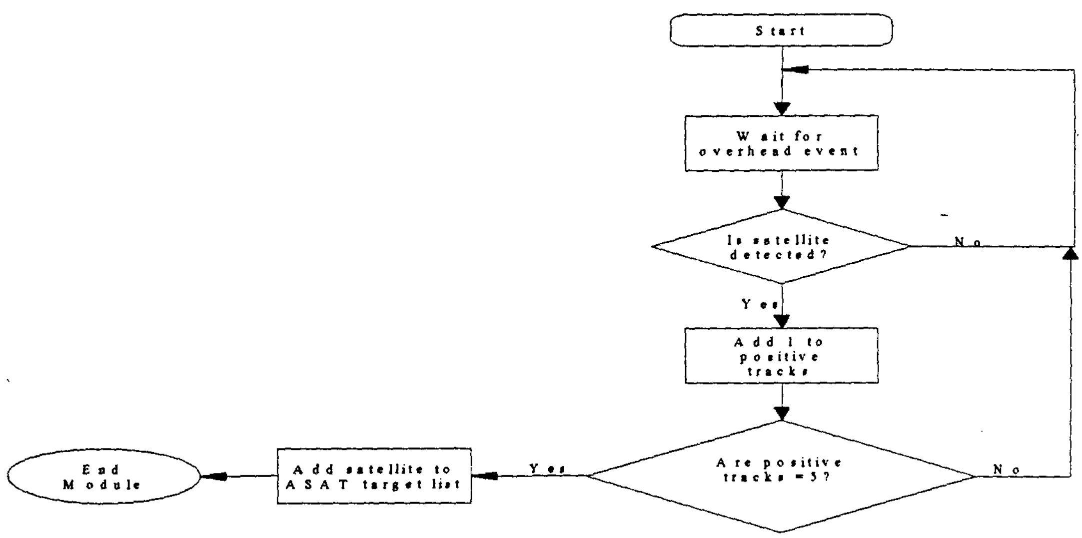

Figure 3-7: Space Surveillance Process

described by the continuous looking model defined in equation 3.6 where D equals the enemy satellite's probability of being detected and identified and T equals the length of the overhead time of the satellite. A random draw against the value calculated in equation 3.6 determines if the satellite is detected and identified. An arbitrary number of

five passes is required before a satellite is placed on the ASAT target list. This number of passes is necessary to insure positive identification of the enemy satellite.

Negation operations will attack all three segments of an enemy's satellite system as shown in Figure 3-8. Negation forces receive information about the enemy space capability from space surveillance and other intelligence reports. Once these reports are received, a decision must be made on which segment must be negated. If the received report concerns a satellite, target information is provided to the ASAT forces. ASAT forces consist of a ground-based directed energy weapon and air-to-space missiles fired from aircraft. The directed energy weapon has a single shot opportunity at each overhead event due to the tremendous amount of power required. However, if the weather is deemed poor, an attack cannot take place because of the atmospheric attenuation caused by clouds. The tasking of the air launched ASAT occurs as any other air tasking mission does. A random draw against the ASAT probability of kill would be taken to determine if the satellite is destroyed. If not, the mission has to be reassigned. An attack against the enemy C^2 segment consists of placing jammers in range to interfere with enemy transmissions. The distance from the jammer and the maximum range of the jammer determines the probability that a transmission is jammed. Equation 3.11 is borrowed from ACES (4:66):

$$\text{Jamming Probability} = 1 - (\text{Distance/Maximum Range})^2 \qquad (3.11)$$

Emissions within the maximum range of the deployed jammer will be jammed this

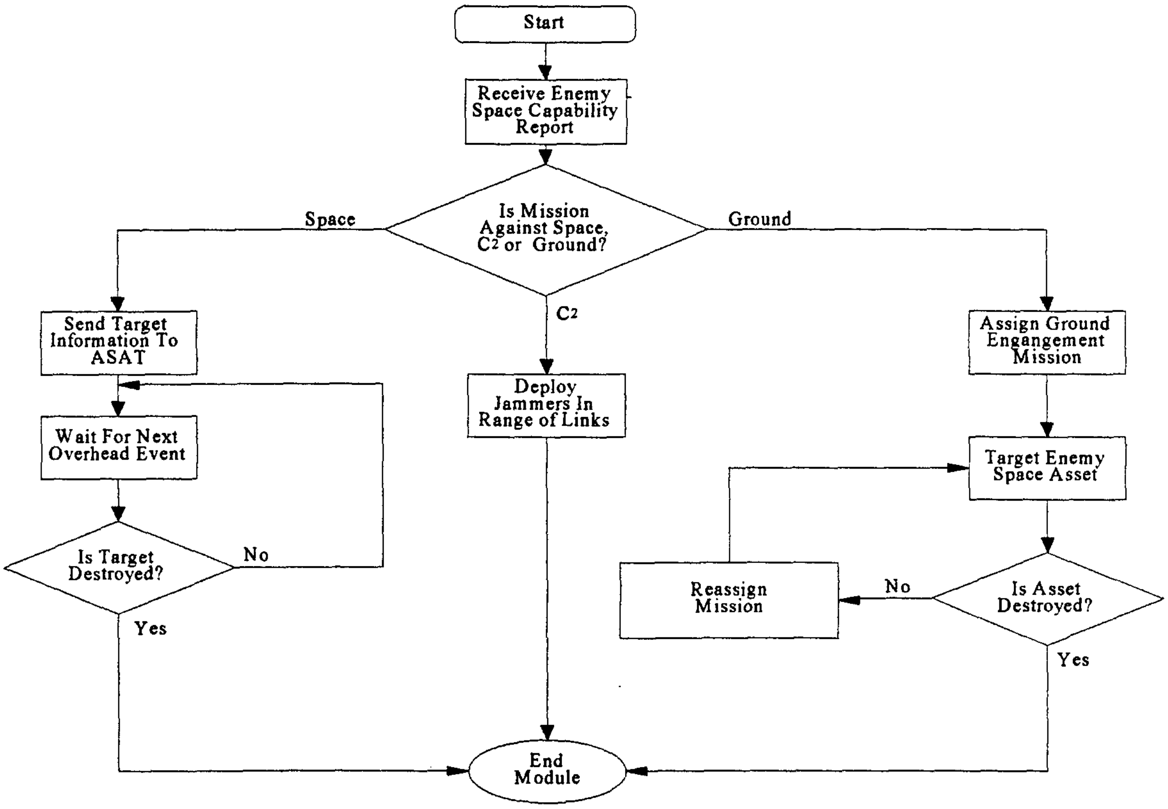

Figure 3-8: Negation Process

percent of the time. The assumption made here is that the jammer is constantly radiating and therefore susceptible to detection by enemy electronics intelligence units. Negation of the ground segment involves the targeting and destruction of enemy ground sites. This procedure is the same as for attacking any other asset.

As stated in Chapter 2, protection of space assets is concerned with inhibiting the enemy's ability to disrupt use of friendly space information. Therefore, the protection of friendly space segments would be defending against the processes described earlier in this section. The protection of spacecraft will be displayed as a decreased probability of kill when attacked by an ASAT weapon. Protection of the other two segments would occur as normally prescribed by a model. C^2 protection involves the destruction of

enemy jammers that are disrupting various transmissions to and from space. Mission planners can protect the ground segment by deploying forces to defend the area.

Satellite Control/Spacelift

Each of these tasks deal with optimizing the satellite constellation above the theater. Satellite control deals primarily with the relocating geostationary satellites while spacelift is performed to augment or replenish the existing constellation. Space Command units outside the chain-of-command of theater commanders handle the satellite control task. However, as demonstrated by Desert Storm, theater commanders have a vital interest in the repositioning of geostationary satellites to improve communications connectivity or early warning capabilities. Due to the worldwide commitments of these systems, movement is not always possible. This task can be simulated by mimicking the process of a theater commander requesting additional coverage from a certain satellite system. Displays of the satellite constellation consisting of commandable satellites with their operational status is given to users of the model for use throughout the game period to supplement satellite coverage whenever necessary. Depending on the scenario, this request can be approved or denied. If approved, the satellite is available for use after the repositioning time is complete. Off-line analysis provides the transfer time. Spacelift, like satellite control, is managed outside the theater. To supplement the existing satellite constellations, theater commanders request additional spacecraft be launched. Again, depending on the scenario, these requests can be approved or denied. If approved, the satellites are available at times specified in off-line analysis.

Logistics of System

A model simulating theater logistics should represent the systems necessary for use with satellites. These systems consist of communications antennas and mobile space command units. The decision to deploy these systems is left up to the model user. If the necessary elements are not in the theater, then the satellite's capability will not affect the theater.

Conclusion

The integration of space forces into a model is a very involved process but is essential to the realistic portrayal of space's impact on the battlefield. This chapter details the modeling of every task performed by spacecraft except for mapping. Mapping is assumed to be a prehostility function providing the playing field. The next chapter will present exactly how these different functions will be placed into the ACES model.

IV. Application

Introduction

The Air Force Command Exercise System (ACES) is a discrete event combat system designed to support intermediate and senior service schools in teaching Air Force doctrine within the context of a theater warfare exercise. Its primary focus is to allow instructors to easily define scenarios that allow specific educational goals to be taught. ACES is a joint wargame modeling the actions of land, air, and sea forces and capable of providing games in which combat units operate at the global, theater, or sub-theater level. Land units maneuver, attack, and bombard. Air units are formed into packages, given missions, and then sent into action. Naval units maneuver, fight, perform antisubmarine warfare (ASW), bombard, and invade (4:5).

ACES views the world as consisting of two types of objects: entities and assets. Entities are logical groupings of other entities or physical items, while assets are the physical items. For example, a squadron entity is a logical grouping of physical aircraft and a division is a grouping of brigades which in turn is a grouping of tanks, trucks, and armored personnel carriers (APCs). An F-16 carrying missiles, bombs, guns, and ammunition is an example of assets attached to another asset. ACES events operate on entities with the results being expressed in terms of their assets. An aircraft package entity attacks an armored brigade entity. The aircraft package entity expends missile assets and the brigade loses tank and APC assets. The introduction of space systems into ACES affects how entities are employed and how they interact with each other. Preliminary orbital analysis defines the overhead event times for satellite constellations. This chapter will focus on the implementation of several of the algorithms outlined in

Chapter 3 into an ACES scenario where the AOI is Korea. Because ACES does not currently model TBMs, the missile warning and ballistic missile tasks are not planned for implementation.

Navigation and Positioning

The influence of GPS is shown in ACES through the movement of ground units and the accuracy of GPS-aided Precision Guided Munitions (PGMs). The GPS state times are defined within the game database and used at the appropriate time step. Exact times of optimal GPS coverage can be computed using the SEM model or some other GPS simulation or nominal times can be set up to achieve certain educational objectives.

Before GPS effects can be accounted for within ACES, GPS assets must be added to the asset dependencies within the game's database. Asset dependencies are defined as those assets which other assets depend on to increase or decrease their capabilities or mount and survive an attack. Armor, for example, increases the chances of an entity to survive. Within ACES, there are four types of dependencies that can be used in a particular game (4:70):

1. Capability Dependencies
2. Survivability Dependencies
3. Attrition Dependencies
4. Consumption Dependencies

GPS receivers are regarded as capability dependencies in that weapons are dependent on them being present to be effective. The game designer specifies these dependencies by indicating which dependencies exist and when they come into effect. For example, a missile requires a launcher when a unit wants to make a missile attack. To accomplish

this, the designer tells the game a capability dependency exists between two specific assets (i.e. missile and launcher). Further, the designer specifies Operation Reaction System (ORS) dependency indicators that, when set to a specified condition, cause the dependency to be considered by the game system (i.e. when launching missiles). The designer then indicates, in each ORS operation, what dependency indicators are set by that operation (i.e. operation launches missiles). Finally, the game designer specifies what type of degradation occurs due to the dependency. This degradation is in the form of a mathematical function that describes the shape of the degradation curve (4:70-71).

With respect to GPS, an arbitrary number of GPS receiver assets are assigned to munitions, air and ground units. The ORS dependency indicators are invoked whenever the munition is fired or the unit considers a move. Dependency indicators are invoked at the impact of a target by a guided GPS munition or the movement of a unit equipped with GPS receivers. To determine the degradation in a munition's performance, the SEP for the munition is computed using Figure 3-1. As the SEP increases, the probability that the target is destroyed decreases.

The ACES system uses a scoring algorithm and movement data for the unit's Operations Order (OPORD) to select a new hexagon (hex) for the unit to move toward as well as the speed at which the unit moves. A basic scoring algorithm computes the score for a single hex based on the unit's speed and use of cover (4:12). The current ACES estimated speed algorithm does not account for the presence of GPS receivers with a unit. GPS effects estimated speed depending on the type of terrain the unit is travelling through and therefore is multiplied by the terrain effect on the unit's speed. The GPS multipliers in Table 3-5 demonstrate the influence of terrain on a unit's GPS receiving

capability which in turn effects a units speed. The estimated speed for a unit within a hex is computed as follows:

$$\text{EstimatedSpeed} = (3.0 + 0.7 / (\text{UnitDisposition} - 0.2)$$
$$* \left[\prod_{i=1}^{4} (1 + (\text{TerrainUsage}) * \text{TerrainFX}(i) * \boldsymbol{\mathit{GPSMultiplier}}) \right]$$
$$* (1 + (\text{RiverUsage}) * (\text{RiverFX})) * (1 + (\text{RoadUsage}) * (\text{RoadFX}))) \qquad (4.1)$$

Where:

- *EstimatedSpeed* is the estimated speed of the unit after considering the terrain features in the location.
- *UnitDisposition* is the fraction of the unit that is forward at a given time.
- *TerrainUsage* is a factor that represents the percentage of the time the unit will be in the terrain as opposed to being on a road or a river.
- *TerrainFX* is a table of values giving the terrain effects on speed for each type of terrain that can exist in the hex.
- *RiverUsage* is the percentage of the time the unit will be using the river as a mode of travel
- *RiverFX* is the river effect on speed.
- *RoadUsage* is the percentage of the time the unit will be using the road as a mode of travel
- *RoadFX* is the road effect on speed.
- *GPSMultiplier* is the value from Table 3-5

Improved navigation through GPS use means that those operating GPS-equipped assets are less likely to get lost and more likely to reach the desired destination.

After adjustments to the score based on expected attrition and the presence of other units, the candidate hex with highest score is then recommended as the next hex to move into (4:15).

Figure 4-1 shows the process of calculating the estimated speed of units.

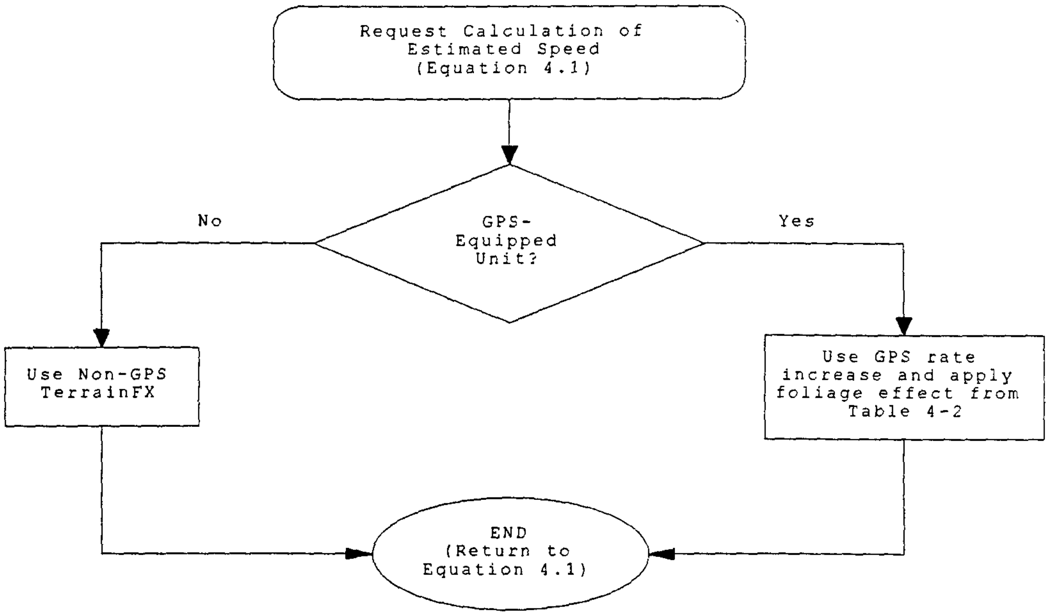

Figure 4-1: ACES Calculation of Estimated Speed

Assume a situation where two units each with UnitDispositions equal to 0.80 are trying to decide which of six hexes to take to proceed toward a target. One unit is equipped with GPS while the other is not. Each hex has the usages as described in Table 4-1.

Table 4-1
Example Terrain, River, and Road Usages

	Terrain Usage	River Usage	Road Usage
Hex 1	0.333	0.333	0.333
Hex 2	1	0	0
Hex 3	0.25	0.25	0.5
Hex 4	0.5	0.25	0.25
Hex 5	0.25	0.5	0.25
Hex 6	0.60	0.10	0.30

All other values for each unit are equal. Each RiverFX value equals 0.25 while the RoadFX equals 2.0. Table 4-2 displays the varied TerrainFX, TerrainFX with GPS access and GPS multipliers for each type of terrain within a hex. This case assumes that GPS enables a unit to move 1.5 times faster than a unit without GPS access. This speed

multiplier is in effect across the different types of terrains. The calculated increase in unit speed is the product of the GPS multiplier and the TerrainFX of a unit with GPS. The GPS multipliers are similar to those in Table 3-5.

Table 4-2
Example TerrainFX Values and GPS Multipliers

	Clear	Mountains	Urbanization	Jungle
TerrainFX	1.5	1	0.75	0.5
TerrainFX w/ GPS	1.5	1.5	1.5	1.5
GPS Multiplier	1	0.67	0.67	0.33

Each unit decides which direction to go using equation 4.1. The only difference is that the unit which is not relying on GPS suffers no degradation effect for traversing terrain which obstructs reception of the GPS signal. The computations of each estimated speed are in Appendix B-1. Solely based on these calculations, each unit selects Hex 2 to travel through. The difference lies in the estimated speeds in which each unit traverses the hex. The GPS equipped unit has an estimated speed of 62.604 while the other unit's estimated speed equals 54.687. Therefore, the GPS unit is expected to move through Hex 2 faster than the other unit. Since ACES employs several other equations before determining the best direction to go, the influence of GPS would only effect this initial calculation. GPS does not decide the final direction taken but it does influence the decision.

PGMs may attack a specific asset category of a target or a particular asset. Currently, the following attrition equations calculate attrition of these assets by PGMs (4:25-26):

$$\begin{aligned}\text{Attrition} = {} & (\text{Strength}) * (\text{UnitVulnerability}) * (\text{ScalingFactor}) \\ & * (\text{NumAssets}) * (\text{AssetVulnerability}) * (\text{AssetMarginalVuln}) \\ & * (\text{PercentVisible})\end{aligned} \tag{4.2}$$

$$* (\text{PercentVisible}) \tag{4.2}$$

$$\text{Attrition} = \min[\text{Strentgh},(\text{Attrition}) * (\text{Allocation} / \text{TotalAllocation})] \tag{4.3}$$

$$\text{Attrition} = (\text{Attrition}) - (\text{SurvivabilityPercent}) * (\text{Attrition}) \tag{4.4}$$

Where:

- *Attrition* is the amount of the asset that is lost due to indirect fire
- *Strength* is the measure of the strength of the attack.
- *UnitVulnerability* is the unit vulnerability to the munition used. This value is dependent on the munition used and the current operation of the target unit.
- *ScalingFactor* is the scaling factor defined for the asset to account for the distance at which the munition is fired from.
- *AssetVulnerability* is the asset's vulnerability to the munition.
- *NumAssets* is the number of this type of asset the target unit has on hand.
- *AssetMarginalVuln* is the asset's marginal vulnerability to the munition.
- *PercentVisible* is the percentage of the asset that is visible.
- *Allocation* is the allocation number assigned to this asset category for this type of munition.
- *TotalAllocation* is the sum of allocations against the target unit's assets.
- *SurvivabilityPercent* is the percentage of survivability attributed to asset dependency.

Each attrition equation is used iteratively. Equation 4.2 computes the initial attrition of an asset or set of assets based on the strength of the attack, the number of a certain type assets being attacked and the different vulnerabilities to the munition. Equation 4.3 has been changed from the formulation described in ACES because in the original form, it allows an attack of strength three to destroy more than three assets. The new formula calculates the attrition of the assets based on the targeting of the munitions. The variable "Allocation" is an assigned real number between 0 and 10 which represents the target value placed on each asset within a unit. The higher the allocation value, the more force engages that asset. "TotalAllocation" is the sum of all the allocation values. The final

attrition equation, equation 4.4, figures the final attrition assessment for each asset based on that asset's survivability percentage. The survivability percentage is the increased probability of survival for an asset due to special protective features such as bunkers or hangers.

The game designer assigns the vulnerabilities of each unit and asset to PGMs. The game engine adjusts each set of vulnerabilities to reflect the varied effects of GPS on PGMs. These vulnerabilities are based on the SEP of the munition as calculated in accordance with Figure 4-2 which is Figure 3-1 adjusted to work within the ACES framework whenever attrition needs to be calculated. As the SEP of the munition increases, the unit or asset is less vulnerable to attack by that munition.

Assume a game player plans a mission with the following initial conditions:

- Strength = 4
- UnitVulnerability = $0.55^{(0.013*SEP)}$ (4.5)
- Scaling Factor = 0
- AssetVulnerability = $0.60^{(0.013*SEP)}$ (4.6)
- NumAssets = 5
- AssetMarginalVuln = $0.60^{(0.013*SEP)}$ (4.7)
- PercentVisible = 0.80
- Allocation = 10
- TotalAllocation = 30
- SurvivabilityPercent = 0

The base of each vulnerability reflects the vulnerability that entity has to a regular gravity bomb. The exponential part refers to the increase in vulnerability with the addition of GPS guidance. The value SEP is the value calculated in Figure 4-2 and the 0.013 is a scaling factor for a GPS munition. Also assume that two of the munitions have P-Code wide-area access and two have C/A access and jamming effect is minimal. The assumption of different types of munitions being fired forces attrition to be calculated

separately for each type of weapon. GPS state for this example is four and S/A is on.

Following the process flow from Figure 4-2, ACES calls this module when the munition is released and attrition must be calculated.

Step 1: The module checks if the munitions are GPS equipped. As shown in the assumptions, both sets of munitions are GPS equipped.

Step 2: For the first set of weapons, the solution method and access is given as P-Code differential and the second set access C/A code transmissions.

Step 3a: This example assumes jamming effect is minimal, therefore the process goes to Step 4.

Step 4: S/A is on.

Step 5: GPS location accuracy for the P-Code munitions is a uniformly distributed value between 2-4 meters as shown in Table 3-3. For simplicity, a value of 3 m is chosen as the initial location accuracy for the P-Code weapons. For the C/A Code weapons, Table 3-3 provides uniform endpoints of 54-76 m because S/A is on. In this case, let the initial location value equals 65 m.

Step 6: At this point in time, GPS state is set at 4. Because of this value, steps 8 and 9 can be skipped and the process can go straight to Step 10a.

Step 10a: The C/A Code weapons do not have any type of differential access and can then proceed to Step 16b. The P-Code munitions have wide-area access and therefore a new SEP must be calculated.

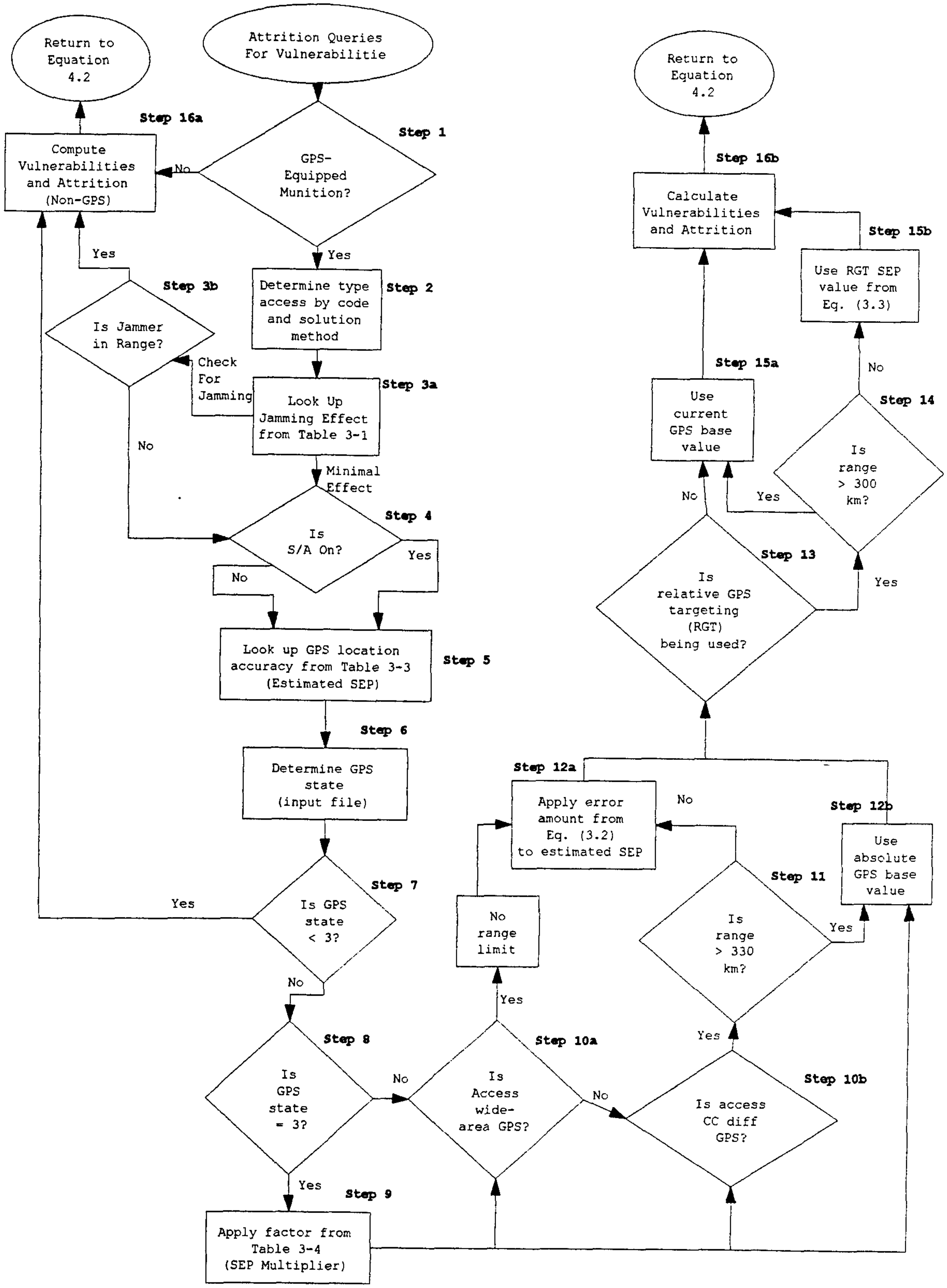

Figure 4-2: ACES Computation of Vulnerabilities

Step 12: Munitions with wide-area GPS access have no range limit to the target but are more accurate when launched near a GPS transmitter. Due to the depth of the targets and the array of surface-to-air sites around the target, the closest transmitter to the launch point is 125 km away. Equation 3.2 adjusts the SEP of the munition to 3.002 m due to the distance from the transmitter.

Step 13: Relative targeting is not used for any of the munitions.

Step 15a: The final base value for the P-Code weapons is 3.002 m while for the C/A Code weapons the location accuracy is 65 m. These values are used to determine the exact vulnerabilities of the targets to each type of weapon.

Step 16b: As shown in Appendix B-2, the unit vulnerability to the P-Code weapons using equation 4.5 is 0.977 while the asset and marginal vulnerabilities are 0.98 according to equations 4.6 and 4.7. For the C/A code munitions, the unit vulnerability is 0.603 and the asset and marginal vulnerabilities are 0.649. The C/A values are in Appendix B-3. Equation 4.2 uses these values to calculate the initial attrition value for each asset.

Step 17: Truncating each value, equations 4.3 and 4.4 yield attrition values of two for the P-Code weapons and zero for the C/A munitions. Therefore, this attack destroys two of the assets. Appendices B-2 and B-3 show all of the calculations.

Appendix B-4 also displays the result of the attack if four regular gravity bombs are used instead. The result of the attack is that only one of the assets is attritted. This result is similar to one in which GPS weapons are used when GPS state is less than three.

The effect of S/A being off instead of on demonstrates itself in the vulnerability value of the C/A code munitions. Instead of the SEP being a number uniformly between

54 and 76, the SEP falls uniformly between 20 and 30. If the SEP is equal to 25, the resulting attrition of the assets is equal to one as opposed to the zero shown in the previous example.

If game players plan attacks when GPS state is less than optimal, the resulting attrition is less than desired. Also, the decision of whether or not to employ selective availability affects both the attrition rates of enemy GPS receivers and those C/A receivers of allies. Each mission where GPS access weapons are the munitions of choice is subject to these decisions.

Power Projection/Air, Land, Sea Defense

The employment of satellites to destroy terrestrial targets is currently not an option for theater commanders and therefore is not appropriate for implementation into ACES at this time. However, the implementation is relatively simple. The process outlined in Figure 3-3 can be directly implemented into the ACES model and utilize equations 4.2 through 4.4 to calculate the attrition of the target. Objects created to perform these tasks are assumed to be low earth orbiting directed-energy weapons. The low earth orbiting assumption allows engagement events to be scheduled based on the overhead time of the satellite. The directed-energy assumption limits the spacecraft to a one shot opportunity making the strength of each attack equal to one as described in equation 4.2. These objects have attributes similar to those of an IMINT satellite in that they are adversely affected by poor visibility over the target. Within the ACES framework, IMINT satellites detect targets according to the following algorithm:

$$\text{FractionalPerception} = \text{BuildupFactor} * \text{ForestationFactor} * \text{Ruggednessfactor} * \text{VisibilityFactor} * \text{SensorFactor} * \text{DepthFactor} \tag{4.8}$$

If FractionalPerception > 0.001, sensor detects enemy assets.

Where:

- *FractionalPerception* is the fractional perception of the unit by the sensor.
- *BuildupFactor* is the level of buildup in a given location.
- *ForestationFactor* is the level of forestation in a given location.
- *RuggednessFactor* is the level of ruggedness in a given location.
- *VisibilityFactor* is the level of visibility in a given location.
- *SensorFactor* is a quantity associated with the given sensor
- *DepthFactor* is the depth of the target (Only used when the target is a submarine)

The process flow for this task is in Figure 4-3. Note that this process incorporates both the image detection and attrition algorithms of ACES. Assume a scenario with the following conditions:

- Strength = 1
- UnitVulnerability = 0.65
- Scaling Factor = 0
- AssetVulnerability = 0.75
- NumAssets = 10
- AssetMarginalVuln = 0.75
- PercentVisible = 0.75
- Allocation = 10
- TotalAllocation = 30
- SurvivabilityPercent = 0
- BuildupFactor = 0.80
- ForestationFactor = 0.50
- RuggednessFactor = 0.20
- VisibilityFactor = 0.85
- SensorFactor = 1

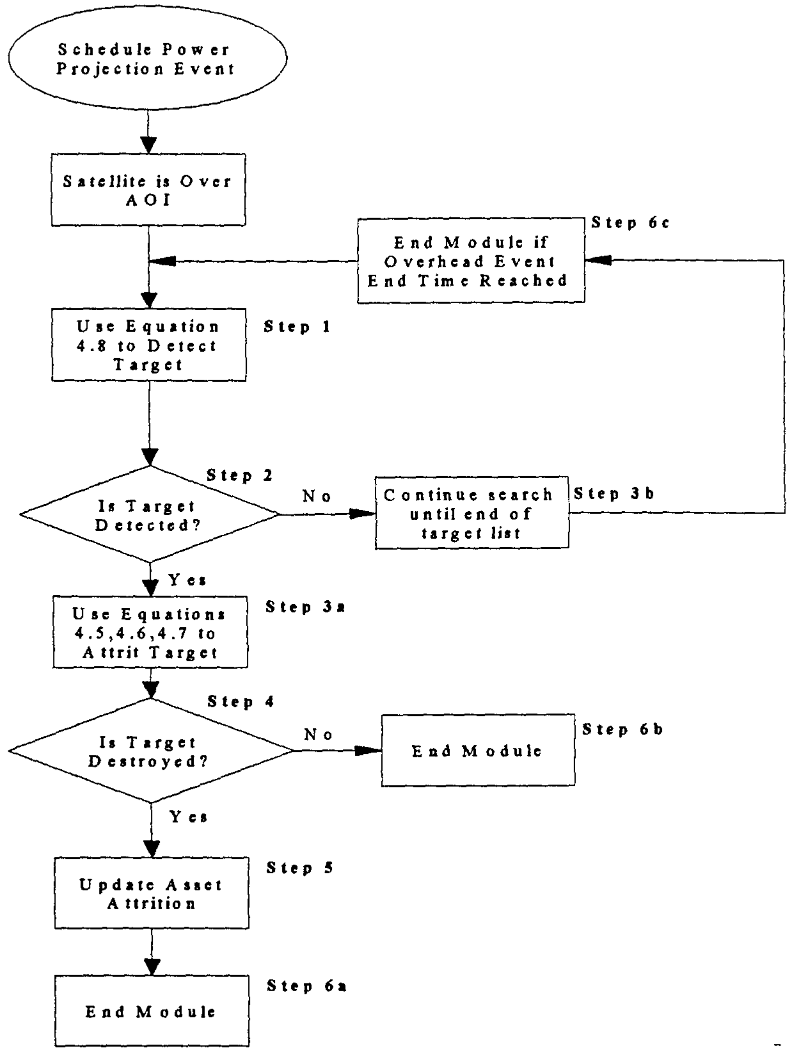

Figure 4-3: ACES Power Protection Process

Step 1: In this case equation 4.8 yields a fractional perception of the satellite of 0.017.

Step 2: Because the calculated fractional perception is greater than 0.001, the satellite detects the unit and can engage a particular asset.

Step 3a: The final attrition result for the target is one.

Step 4: Because the attrition value is equal to one, one of the assets within the unit is said to be destroyed.

Step 5: ACES removes the one destroyed asset from the unit.

Step 6a: After the destruction of the asset, control reverts back to the main program.

Note that if the visibility of the target goes below 80%, the target is detected but the satellite does not destroy it. All calculations are in Appendix C.

Intelligence and Surveillance

The ACES intelligence model simulates the flow and processing of intelligence in the wargame environment. This model is invoked whenever ACES executes an intelligence event or when any other object in the system requests intelligence processing. The components of the intelligence model are:

- Interpretation and analysis of data
- National intelligence data
- Fusion of data, and
- Distribution and reaction

Dedicated information collection objects within the wargame provide all the data to be processed by the Intelligence (Intel) object. The collection system explicitly provides SIGINT, IMINT , HUMINT data while the National Intel Collection object builds intelligence data based on points which are allocated by the players (4:62). These objects do not represent the orbital dynamics of satellite systems.

Because ACES is an event stepped model, spacecraft dynamics can be displayed by scheduling information gathering events at times which reflect the overhead times of low earth orbiting satellites. A generic constellation of low earth orbiting intelligence satellites is set up and overhead event times are added to the event queue. At these times,

intelligence information will be regularly gathered. As seen in Figure 3-4, satellites continue to detect targets until they are no longer over the area of interest. Because intelligence from space is more secure than other forms of intelligence gathering, the retrieval of this information is fairly certain. Other intelligence gathering forces, such as reconnaissance aircraft, can be tasked whenever data is required at intervals other than those where space intelligence data would be available. With the dynamic nature of space intelligence forces modeled, game players can focus attention on other missions besides aerial reconnaissance. As an intelligence gathering medium, aircraft have the drawback of being vulnerable to enemy surface-to-air weapons and are limited to how deep into enemy territory they can fly. Satellites overcome these limitations but do not have the convenience of providing data in a timely manner. By successfully integrating aerial reconnaissance, HUMINT, and space intelligence forces, game players can potentially make better decisions because they receive more and better information from a variety of sources.

The ACES Intel object provides interpretation and analysis of raw intelligence data. While some incoming data, like observed unit position and asset information, does not require interpretation, other data, like emissions data, do require interpretation. The Intel object processes this data to determine the type and level of intelligence to be derived from it. The amount of intelligence derived is a function of the collection mechanism, the level of detection, and previously available intelligence about the area or subject. The collection mechanism can be an emissions detector, IR/photographic platform, or other information gathering device. The level of detection refers to whether the intelligence report is part of the platform's primary or secondary mission and the

duration of the detected signal. The successful integration of all the intelligence gathering platforms at the disposal of game players improves the information about individual targets based on successive detections by the various objects (4:62).

The satellites modeled in ACES are IMINT and SIGINT. Equation 4.8 describes the process of IMINT detection. At each overhead event of an IMINT satellite, equation 4.8 determines if the satellite can see a unit. If the fractional perception is greater than 0.001, then an intelligence report is built for each asset of the detected enemy unit. ACES models SIGINT sensors with the following algorithm (4:64-65):

RandomNumber = random number in (0,1)

$$\text{CTime} = 60 * \text{Duration} - (\text{MinimumScanTime} + \text{RandomNumber} * \text{MaximumVariation}) \tag{4.9}$$

Where:

- *Duration* is the duration of the signal and calculated by:

  RandomNumber = random number in (0,1)

  $$\text{Duration} = -\ \text{MeanDuration} * \ln(\text{RandomNumber}) \tag{4.10}$$

  Where:

  - *Duration* is a real number duration of emissions (in seconds).
  - *MeanDuration* is the mean duration of the radio network, from the game database.

- *MinimumScanTime* is the minimum time for the sensor to spend on a signal in scanning (in seconds), as defined in the game database.

- *MaximumVariation* is the maximum variation for a signal scan/lock time, which is also defined for that sensor in the game database.

If CTime is greater than zero, the sensor intercepts the signal and forwards an

intelligence report.

The suggested intelligence process within ACES is diagrammed in Figure 4-4. Note that the satellites continue searching until the end of the overhead event cycle.

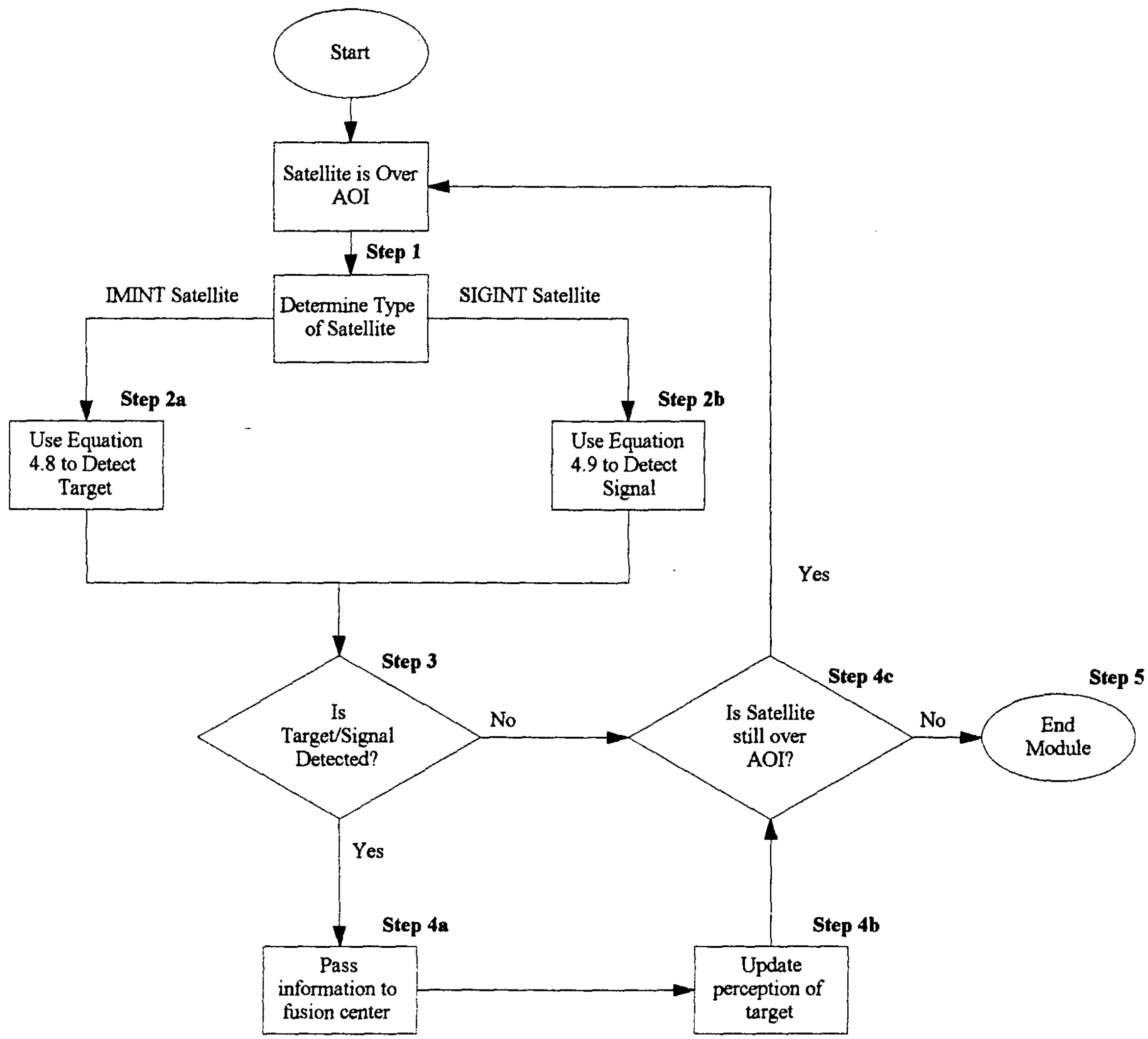

Figure 4-4: ACES Intelligence Collection Process

Assume a situation where a unit has the following variable definitions:

- BuildupFactor = 0.80
- ForestationFactor = 0.50
- RuggednessFactor = 0.20
- VisibilityFactor = 0.05
- SensorFactor = 0.95
- MeanDuration = 0.5 sec

- MinimumScanTime = 45 sec
- MaximumVariation = 15

Both satellite systems are capable of detecting the unit. Assume also that each satellite is in low earth orbit.

Step 1: A satellite occurs at a certain time.

Step 2: ACES must decide which type of satellite event this is. For the purposes of this example, let the first event be the IMINT event and the second be the SIGINT event.

Step 3a: According to equation 4.8, the fractional perception of this unit is 0.00095. Equation 4.10 renders a message duration value equal to 0.9576 which leads to a CTime of 11.0845.

Step 4: Since Step 3 yields a value of 0.00095 fractional perception which is less than 0.001, the unit is not detected by the IMINT satellite. However, the CTime of 11.0845 is greater than 0 so the SIGINT satellite detects the unit.

Step 5a: The SIGINT satellite passes the gathered information to the Intel object for analysis and interpretation.

Step 5b: The Intel object updates the available intelligence data about this unit based on the SIGINT intelligence data and disseminates the information to friendly units.

Step 5c: ACES checks to see if the overhead event time for each satellite has passed. If not, the satellite will move to another hex and repeat the cycle again.

The example output of this process is shown in Appendix D.

Weather

ACES displays the current weather within a particular hex which includes surface conditions for winds, temperature, precipitation, wind speed and direction, electrical disturbances, and visibility in various altitude bands (4:9). The GRC model outlined in Chapter 3 predicts the weather for a target hex and uses this information to establish the Standard Conventional Loads (SCLs) for the aircraft assigned to the mission. Within ACES, game players specify SCLs in the Air Tasking Order (ATO) or allow the ACES Decision Logic System (DLS) to choose an SCL (4:32). The DLS selects which munition load an aircraft should carry when it leaves for a mission. It also tells aircraft what munition to drop on a target when it flies over and tells artillery what munition to fire at different kinds of units. Up to three suggestions on which weapons to dispense are made based on the current situation as defined by the game designer. Typically, the DLS looks at the aircraft type and the intended target to recommend a combat load (23).

Incorporating the GRC model into the DLS requires munitions to be selected based on the forecasted weather as well as target and aircraft type. Model objects simulate DMSP satellites by orbiting the earth in sun-synchronous orbits which provide detailed weather reports over an area twice a day. At these times, highly accurate weather data are provided to theater forces for use in mission planning. Particular weather patterns throughout the AOI are predicted based on a probability of detecting that type of weather by equation 3.8. Because weather areas and states are definable with the ACES database, the satellites can "predict" the weather in each defined area against what the actual weather will be at a later stage in the game (4:9). Other weather forecasting elements can augment this satellite data but with less reliability. ACES

players begin each day of the simulation by receiving reports on the outcome of the previous day's actions. With these reports, weather reports are handed out to help in planning that day's missions. Either game players or the DLS take the weather information gathered at that point and plan operations.

At the target, the DLS, in accordance with Figure 3-5, dispenses the weapons and ACES calculates the results. The weather over the target is rated as to the type of munitions that can best perform in that weather. As seen in Figure 3-5, ideal weather allows the decision on what type of munition to load to be based on the target and mission type. As the weather worsens, munitions designed for use in inclement weather conditions are chosen.

Game players must decide when to schedule missions. GPS state affects this decision as well as the expected weather over the target. If players decide to proceed despite of predicted poor weather, the effects are shown in the attrition of the target.

Assume a mission against an enemy compound consisting of a six buildings with the following simplifying assumptions and initial conditions:

- Four types of weather ranging from 1 to 4 with 1 being the best and 4 being the worst forcing a No Go decision.
  - Weather 1 and 2 allow any type of munition to be loaded.
  - Weather 3 calls for all-weather munitions to be loaded
- Target vulnerabilities to four laser guided munitions (LGMs) are:
  - UnitVulnerability = 0.85
  - AssetVulnerability = 0.975
  - AssetMargVuln = 0.975
- There are four GPS weapons equipped with P-Code receivers and INS without differential access.
  - Assume Initial SEP = 16
- $\text{UnitVulnerability} = 0.50^{(0.013*\text{SEP})}$ (4.11)
- Scaling Factor = 0
- $\text{AssetVulnerability} = 0.55^{(0.013*\text{SEP})}$ (4.12)
- NumAssets = 6

- $\text{AssetMarginalVuln} = 0.55^{(0.013*\text{SEP})}$ (4.13)
- PercentVisible = 0.90
- Allocation = 10
- TotalAllocation = 50
- SurvivabilityPercent = 0

Assume the initial weather report provided by the satellite is a two. This means that the weather is not completely ideal but is acceptable to fly a mission. The selected weapon load for this type of weather is a mix of laser and GPS guided munitions. When the mission is flown against the actual weather, a variety of results can occur. If the weather is as predicted, targets are killed in accordance with the vulnerabilities of each type of munition. Note that the accuracy of the GPS weapons is based on the state of the GPS constellation over the AOI instead of the weather. Assume for this case that GPS state during the mission is three. Following the attrition process described in Figure 4-2, the four LGMs attrit three of the targets while the GPS weapons attrit only two targets.

If the weather is better than expected, attrition is less than desired because too few LGMs are used. Equations 4.2, 4.3, and 4.4 yield attrition of all six targets if the aircraft loads total eight LGMs.

Conversely, if the weather is worse than expected, the LGMs are rendered virtually ineffective. The poor weather effects the visibility of the target to the LGMs which need to see the target to destroy it. If the weather reduces the total visibility to 0.25, then the LGMs do not destroy any targets. Any attrition to the targets comes from the GPS munitions because their visibility depends only on the percentage of the target that is visible. LGMs may be used to attack targets in other areas or, if the weather is much worse than expected, may have to be jettisoned. If there is not a secondary set of targets, the LGMs could be brought back to base.

If the predicted weather variable at the outset of the process is equal to three, then the effects are similar except that the major weapon of choice are GPS weapons instead of LGMs. However, if the weather variable over the target is actually equal to four, the weapons are jettisoned because the mission should not have been flown anyway.

Communications

Although the ACES communication module does an acceptable job modeling communications connectivity, certain aspects of space can be implemented to bring out the effects of space communications on command and control in the theater. Aside from the redefining of networks, the processing of messages remains the same.

The ACES communication model simulates the usage and effects of a military communications system in the wargame environment. These effects include transmission delays and failures, the generation of detectable emissions, transmission network status, and degradable communications. To model explicit communications, the game developer defines explicit radio networks in the game database. All messages that pass between units subscribing to any of these networks must cross these links and are subject to blocking, delays, jamming, interception, and loss directly resulting from the characteristics of those networks (4:59).

ACES defines networks by the type of messages that pass over them. The nine types of messages in the current wargame are (4:60):

- Air Messages
- Artillery Messages
- Communications

- Default Network Type
- Duty Cycle
- Ground Messages
- Intelligence
- Logistics
- Naval

Certain communications events generate these messages during game play. These events include (4:60):

- Air Operations
- Artillery Missile Operations
- Combat
- Emissions
- Intelligence Processing
- Logistics Operations, and
- Reaction Processing.

Space communications affect the communication processing by increasing the distance in which units may communicate with each other and improving the reliability of the communications link. The types of networks defined by ACES can be grouped into the networks described in Figure 3-6 describes. For example, ground operational orders (OPORD) and Air Tasking Orders (ATO), which are ground and air messages respectively, are broadcast from higher headquarters over a satellite link to the required units. Further dissemination of the message to subordinate units occurs over LOS or troposcatter links depending on distance. The Navy typically uses satellites to communicate between ships and therefore connects to the satellite links. Marine units make extensive use of HF links for both short-haul tactical voice and data networks, and

long-haul point-to-point or broadcast networks (32:59). Therefore Marine units are assigned to the HF link. Air Force units make use of all three communications links. Aircraft use LOS communications to communicate with each other and airspace controllers. Broadcast messages transmitted over satellite links are backed up by troposcatter links between bases (22:43) Communications across services generally take place over satellite links.

ACES assigns links to communications network messages based on the type of units involved as shown above. Intelligence messages travel from satellites to processing centers and from the processing centers to necessary units. The transmission of intelligence messages to individual units takes place over a variety of links. ACES uses the default network to transmit messages if the initial network is unable to transmit the message (4:61). In accordance with Figure 3-6, the default network becomes a backup link specified for each type of message. If the backup link is unavailable, the message must wait until a link is available.

When a "transmit message" event occurs in ACES, the message will either be blocked, time will run out, or the message will reach the receiving unit. If it is blocked, a new "transmit message" event will be scheduled for that message at game time of CurrentTime + RetryInterval, unless MessageExpirationTime comes first. If the MessageExpirationTime arrives first, a decision is made to either drop the message or schedule its receipt. CurrentTime represents the current game time and RetryInterval is the transmission retry interval defined for the given radio network. The game time at which the message will no longer be transmitted is the MessageExpirationTime (4:60).

If the MessageExpiration Time is reached, the system checks a value called ExpirationAction to see if the message is automatically received or dropped. If ExpirationAction has a value of "Drop," then the message is dropped, otherwise, if the value is "Deliver," and the system schedules an event to mark the reception of the message (4:60).

A message can be blocked for any of the following reasons (4:60-61):

- Either the sender or receiver of the message is dead;
- One or more of the critical entities on the network has poor comm status;
- The network is saturated with message traffic;
- Poor weather, and the network is not sufficiently shielded; or
- Enemy jamming effects.

If the message is not blocked, an event is scheduled for "message receipt" at a receipt time that takes into account the network delay time an processing time at the receiver. The algorithm for computation of receipt time is as follows (4:61):

RandomNumber = random number in (0,1)

NetworkDelay = min(3 * MeanDuration,

MeanDuration * -ln(RandomNumber)) (4.14)

ReceiptTime = CurrentTime + NetworkDelay + ProcessingDelay (4.15)

Where:

- *NetworkDelay* is the calculated delay for the message crossing the network.

- *MeanDuration* is the mean duration of a message on the network, defined in the game database.
- *CurrentTime* is the current game time.
- *ProcessingDelay* is the delay due to processing and distribution at the receipt node, defined in the game database as a characteristic of the network.
- *ReceiptTime* is the game time for receipt of the message.

The variables in equations 4.14 and 4.15 represent the links described in Figure 3-6. The use of varied communication systems shows the diverse nature of theater communications and the benefits and pitfalls associated with each. Game players should experience the differing needs of combat forces for communications connectivity.

Space Control

ACES scenarios generally portray theater combat in Northeast or Southwest Asia. Because the potential enemies in these areas have no space capability, the task of negation is not needed. In either of these scenarios, space surveillance assets only provide game players with updates on the status of friendly space forces. However, regardless of the region where the game is played, deployed space forces must be protected. Protection of these forces occurs explicitly and implicitly. Explicitly, armed units deploy in the vicinity of ground segments to insure uninterrupted service. Anti-aircraft batteries deployed around a communications hub are an example of protection. Protection of the C^2 segment is implicitly displayed in the jam resistance values of space communications systems. Satellites are protected implicitly with a reduced vulnerability to ASAT weapons. These examples illustrate the wide variety of protection methods taken to defend spacecraft.

In scenarios where the enemy has a space segment, all three space control tasks become vitally important. Since ACES does not model space, all assets and decision processes associated with these tasks must be added to the game's database and decision control logic. Players periodically receive implicit space surveillance reports as part of the daily intelligence reports. A sample of a space surveillance report is in Appendix E. These surveillance reports contain the type of satellite, which side owns it, and the time it will overfly the area. Like other intelligence reports, players use the space surveillance reports to plan future actions.

Game players schedule negation activities based on the received intelligence and space surveillance reports based on the enemy's perceived space threat. Figure 3-8 describes the decision making process for negation missions. A space surveillance radar asset is available to players for deployment in the theater. Missions against the enemy's space segment utilize reports from the deployed radar for tracking and targeting. Opportunities to track satellites occur during the overhead event times of the enemy satellites. Each satellite has a level of vulnerability to radar detection. Before the radar forwards tracking information to negation units, it must continuously track the satellite. After a set number of successful tracks, ASAT forces receive the tracking information and add that satellite to a target list. Whether or not action is taken against the satellite depends on the game player scheduling a space interdiction event. Either the directed-energy ASAT weapon or an air-to-space missile fired from an aircraft can engage enemy satellites. Scheduled anti-satellite missions occur at the next overhead event time. Each satellite has a vulnerability to each of these weapons and random draws against this vulnerability decide if the weapon destroys the spacecraft. Weather affects the decision

to use the directed-energy weapon. Clouds and precipitation render this weapon ineffective.

Negation operations against the enemy's ground and C^2 segments target assets that receive information from and control the opponent's space forces. These assets include any unit or facility involved in space operations, such as communication nodes, mobile command and control units, and space launch facilities. ACES assigns and executes negation missions. Besides attacking the C^2 with jamming, turning S/A on disrupts the link between enemy GPS receivers and GPS satellites. As mentioned in the section on navigation and positioning, the SEP and the resulting asset vulnerability decrease with the employment of S/A.

The following example of the space surveillance and negation tasks shows how these tasks work together and result in the times the satellites are finally destroyed. The simplifying assumptions are:

1. The ASAT weapon is chosen to interdict the satellites;
2. The weather at the time of interdiction is clear;
3. The ASAT assigns target priority of the satellites destruction in the order they are detected;
4. The ASAT does not target another satellite before the previous satellite is destroyed;
5. The satellite must be tracked five times before it is available for the ASAT target list.

A generic SLAM simulation system demonstrates how long it would take for a space surveillance system to track satellites five times and the time it takes for the ASAT to destroy each enemy satellite. The example simulates a generic satellite constellation

consisting of three satellites with the specified overhead times as displayed in Table 4-3, where time is measured in seconds.

Table 4-3

Example Space Control Initial Conditions (Times in seconds)

	ELINT	SIGINT	IMINT
Time Between Overhead Events	5700	54900	6000
Overhead Event Duration (sec)	1200	600	450
Detection Vulnerability	0.95	0.80	0.85
ASAT Vulnerability	0.65	0.60	0.50

Once the space surveillance continuously tracks a target, the satellite is passed to the ASAT weapon for targeting and destruction. At the next overhead event, the ASAT weapon attacks the satellite with a probability of destruction equal to the satellites ASAT vulnerability. This simulation model is run 100 times to obtain the averages on the time until the satellite is available for ASAT targeting and time of destruction for each satellite.

It is clear from the results displayed in Appendix F-1 that the targeting and destruction of all three satellites will take between 4.03 and 9.81 days. The ELINT satellite which is in the lowest orbit is the first to be destroyed followed by the IMINT and SIGINT satellites respectively. This can be attributed to the number of passes made by each satellite. The more passes a satellite makes per day, the more chances it has to be destroyed, thereby shortening the time till destruction. Table 4-4 displays the range of

times it takes to target and destroy each satellite.

Table 4-4

Example Satellite Targeting Destruction Time Ranges (in hours)

	Time Till Available To ASAT		Time Till Destruction	
	Minimum	Maximum	Minimum	Maximum
ELINT	10.42	16.21	12.33	23.83
IMINT	23.06	28.33	24.83	35.56
SIGINT	81.39	189.44	96.94	235.56

The satellite keeps performing its mission until the ASAT destroys it. After the time of destruction, the satellite is no longer available to perform its mission.

Space Support

The tasks within the space support function are satellite control, spacelift, and system logistics. These tasks involve establishing a cohesive space network to support theater forces. Within the framework of ACES, they allow game participants to play an active role in the establishment and preservation of a satellite constellation and the supporting ground segment. To simulate the satellite control process, game players periodically receive displays of the satellite constellation, consisting of commandable satellites with their operational status. Depending on the educational objective, requests for satellite movement are approved or denied. If approved, the field of view of the satellite changes at the scheduled event time and the impact is shown as earlier described for that satellite system. Changes to a satellite's orbit take time so the satellite is not available for service until it arrives at its destination. Similarly, spacelift occurs in response to requests for additional satellite coverage. Upon approval, a satellite

activation event is scheduled and information from that system is available after the event time. The time for a newly launched satellite to be ready to perform its mission hinges on the time it takes for the satellite to achieve orbit and receive its early orbit check from Space Command satellite controllers. If the learning objective is for the students to see the vast difference in operations with and without satellite coverage, delay times can be adjusted accordingly. The additional satellite coverage affects the game by providing more information after the satellite is in place.

The ACES logistics system handles all aspects of requesting, transporting, and supplying both conventional and nuclear resources (4:51). Within this system, the ground segments which support space provide transportation throughout the theater. The existence of these units in theater determines whether or not information from some satellite systems can be accessed. If a unit does not have an antenna capable of satellite communications, then that unit is not able to use the satellite constellation to communicate. Other deployable assets include GPS relay transmitters, mobile missile warning units, mobile weather ground stations, and ASAT weapons. These systems support the established space segment by either retrieving the gathered information or extending the capabilities of space systems. If the deployment of these assets is not an educational goal of the game, ACES models them in the theater implicitly.

Conclusion

Because ACES does not model satellites explicitly, much work must be done to include satellite assets into the model. Once satellite assets are created, the effects of space can be effectively shown to game players. The primary educational advantage of

these additions to ACES is the increase of awareness game players receive of the dynamic nature of space systems. Students should leave an ACES scenario with knowledge that is applicable to future operations. Game players should understand that satellite systems are not always available and therefore call for other assets to complete certain tasks. Space systems provide another means to secure information to dissipate the fog of war. As seen, space systems influence a number of decisions and should be considered before each major undertaking. The model changes specified here, even in a nominal, unclassified form, should educate ACES players on some of the benefits and drawbacks of space systems.

V. Summary, Recommendations and Conclusions

Summary

At the outset of this project, five questions were to be answered by this research. Those questions were:

1. What do Air Force leaders need to know about space?
2. How are space systems currently being modeled in theater level simulations?
3. What can be extracted from other models to incorporate into ACES?
4. What is the best way to incorporate space into existing campaign models?
5. How should this information be passed to wargame players?

What do Air Force leaders need to know about space?

Desert Storm, touted as the first Space War, displayed the tremendous effect that space forces can have on the outcome of a war effort. Space forces affected every level of war--strategic, operational, tactical--and warfighters from the decision maker to the shooter. Because models are so widely used for training and decision making, the influence of space should be shown in the outcomes that are derived. The key attribute of space that needs to be understood is that satellites are not always available to provide information acquired in the performance of their mission.

How are space systems currently being modeled in theater level simulations?

Of the seven simulations analyzed, five are campaign level, one is mission level, and one is a communication protocol designed to connect models which are not designed to work together. Of the campaign models, each attempts to simulate at least one of the

tasks within the force enhancement function. However, no attempts are made to model satellite systems explicitly. The mission level model, EADSIM, models satellites in a wide variety of tasks explicitly. This would seem intuitive because the Theater Missile Defense mission is heavily intertwined with the functions of space forces to provide warning, intelligence, and communications. EADSIM also models some force application tasks by simulating satellites interdicting terrestrial forces as well as theater ballistic missiles. The ALSP Confederation is designed to connect disparate models in an attempt to efficiently handle each mission performed by the services. Models simulating a variety of space functions are planned for inclusion into the confederation in the near future. Currently, PSM provides the confederation with missile warning data while TACSIM provides intelligence and surveillance from space.

What can be extracted from other models to incorporate into ACES?

None of the analyzed simulations provided an acceptable methodology for incorporating space into ACES. EADSIM explicitly models satellites and their functions in a way which may be too complex for implementation at the theater model level. The ALSP Confederation introduces the idea of allowing a more detailed model to handle the processing of satellite information and providing that information to the theater level model to influence its actions. The problem with the ALSP concept is the development of a common communication protocol could be very difficult. Also, many mission level models which would be required tend to be very data intensive requiring many man-hours for database customization and accredidation.

However, other less known models provide functional algorithms for determining space effects with a theater level wargame like ACES. The Rand TLC/NLC model has a

methodology for determining the aggregate effect of GPS on theater campaigns. This methodology takes into account the number of GPS satellites over the AOI in the calculation of GPS effects as well as a wide variety of GPS solution methods. The GRC Weather model allows the use of weather information from space to influence the choice of aircraft loads prior to missions. A change made to the algorithm allows for new weather data to be passed only after subsequent passes of a modeled weather satellite. These models are ideal for introducing the decision making that must accompany the use of satellites during mission planning.

<u>What is the best way to incorporate space into existing campaign models?</u>

Before space can be incorporated into a theater model, users must seriously and critically compare their model to a real world situation such as seen in Desert Storm to see where space could influence the interactions within that particular model. Without this determination, space forces will be either misapplied or completely ignored.

As seen in the modules displayed in chapter III, space can be incorporated in the form of basic subroutine calls. Satellites need not be directly modeled to display the influence of space. The processes diagrammed in chapter III detail the major steps that need to be considered in regards to each task. The key feature of each process is the availability of satellite information to end users.

<u>How should this information be passed to wargame players?</u>

The future of warfare is heavily dependent upon space and this fact must be better displayed in models used for analysis and training. Players of wargames should realize the true dynamic nature of space forces. The space functions of force enhancement, force application, space control, and space support need to be explored to present a

complete picture of all that is involved with performing missions in space. This will lead to space being viewed at as a place where missions are performed and not a mission itself. Players should be part of decisions that optimize the use of space forces. As described in Chapter IV, engagement decisions often hinge on the presence of space forces above the target. Overhead times then become an important part of the information provided to decision makers when they formulate mission taskings. Space forces should be integrated into the framework of the game to allow players to learn about space forces and make combat outcomes more realistic.

Recommendations

While some of the algorithms presented are simple, they do provide the basis of what each particular function entails. The next logical step for this research is the actual implementation of the detailed modules into specific models and in particular, ACES. The modules described in Chapter IV demonstrate how each space task should work with the equations and algorithms of ACES. For other models, researchers must determine the purpose of the model in question and define how space influences that purpose. While the many of equations will change, the underlying processess will be the same regardless of the model.

Conclusion

This study focused on combat modeling and the role of functions performed by satellites within those models. An introduction to the missions performed in space and the uses of simulations and models was presented. Six widely used theater level models and a simulation protocol were analyzed to see how space functions are portrayed within them. The explicit representation of space forces is lacking in these models. A

methodology was presented to incorporate all of the space functions except mapping. This methodology was then applied to the ACES wargame to assist in the education of senior service school students. Further research in this area centers on the actual implementation of these algorithms into specific models.

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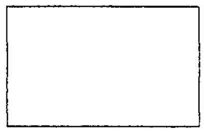
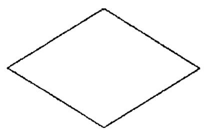
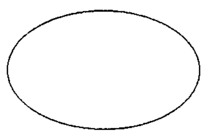
Appendix A: Flowchart Legend



Action to take



Question to answer



Change of model control

Appendix B-1: ACES Movement Example

Below are the calculations to show how GPS use could change the hex of choice for a unit planning a move. Calculations are made for one unit with GPS access and one without GPS access. Each unit is attempting to decide which hex to travel to next. The first decision to be made in the decision algorithm is the scoring of each hex based on estimated speed within the hex.

Amount of troops forward for each unit $\quad UnitDisposition := 0.80 \quad$ Counter $\quad j := 0..5$

Usage vectors for the six hexes

$$RoadUsage := \begin{bmatrix} \frac{1}{3} \\ 0 \\ 0.5 \\ 0.25 \\ 0.25 \\ 0.30 \end{bmatrix} \quad RiverUsage := \begin{bmatrix} \frac{1}{3} \\ 0 \\ 0.25 \\ 0.25 \\ 0.5 \\ 0.10 \end{bmatrix} \quad TerrainUsage := \begin{bmatrix} \frac{1}{3} \\ 1 \\ 0.25 \\ 0.5 \\ 0.25 \\ 0.60 \end{bmatrix}$$

Effects of each type of terrain on the units--The first column of the TerreainFX matrix is for units without GPS and second one is with GPS.

$$RoadFX := 2 \quad RiverFX := 0.25 \quad TerrainFX := \begin{bmatrix} 1.5 & 1.5 \\ 1 & 1.5 \\ 0.75 & 1.5 \\ 0.5 & 1.5 \end{bmatrix} \quad GPS := \begin{bmatrix} 1 \\ 0.67 \\ 0.67 \\ 0.33 \end{bmatrix}$$

Transformation of river and road variables

$$River_j := 1 + RiverUsage_j \cdot RiverFX \qquad Road_j := 1 + RoadUsage_j \cdot RoadFX$$

Calculation of Estimated Speed Scores of the Unit With GPS for each Hex:

$$EstimatedSpeed_j := \left(3.0 + \frac{0.7}{UnitDisposition - 0.2}\right) \cdot \left[\prod_{i=0}^{3} \left(1 + TerrainUsage_j \cdot TerrainFX_{i,1} \cdot GPS_i\right)\right] \cdot River_j \cdot Road_j$$

$$EstimatedSpeed^T = (\ 23.43 \quad 62.604 \quad 21.419 \quad 32.728 \quad 17.01 \quad 43.271\ )$$

Calculation of Estimated Speed Scores of the Unit Without GPS for each Hex:

$$EstimatedSpeed2_j := \left(3.0 + \frac{0.7}{UnitDisposition - 0.2}\right) \cdot \left[\prod_{i=0}^{3} \left(1 + TerrainUsage_j \cdot TerrainFX_{i,0}\right)\right] \cdot River_j \cdot Road_j$$

$$EstimatedSpeed2^T = (\ 21.943 \quad 54.687 \quad 20.33 \quad 29.961 \quad 16.145 \quad 39.158\ )$$

Appendix B-2: ACES P-Code Attrition Example

The following is an example of the attrition of a number of assets by two guided munitions with P-Code wide-area differential GPS access

Definition of Attrition Variables:

$SEP := 3.001$ $\quad$ $strength := 2$ $\quad$ $percentvisible := 0.80$ $\quad$ $scalingfactor := 1$

$Allocation := 10$ $\quad$ $TotalAllocation := 30$ $\quad$ $survivabilitypercent := 0$ $\quad$ $numassets := 5$

$assetvuln := 0.60^{0.013 \cdot SEP}$ $\quad$ $margvuln := 0.60^{0.013 \cdot SEP}$ $\quad$ $unitvuln := 0.55^{0.013 \cdot SEP}$

$assetvuln = 0.98$ $\quad$ $margvuln = 0.98$ $\quad$ $unitvuln = 0.977$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 7.51$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{Allocation}{TotalAllocation}\right)^{strength}\right) \qquad Attrition_2 = 2$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 2$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$floor\left(Attrition_{final}\right) = 2$$

Appendix B-3: ACES C/A Code S/A on Attrition Example

The following is an example of the attrition of a number of assets by two guided munitions with C/A Code GPS access when S/A is turned on.

Definition of Attrition Variables:

$SEP := 65$ $\quad$ $strength := 2$ $\quad$ $percentvisible := 0.80$ $\quad$ $scalingfactor := 1$

$Allocation := 10$ $\quad$ $TotalAllocation := 30$ $\quad$ $survivabilitypercent := 0$ $\quad$ $numassets := 5$

$assetvuln := 0.60^{0.013 \cdot SEP}$ $\quad$ $margvuln := 0.60^{0.013 \cdot SEP}$ $\quad$ $unitvuln := 0.55^{0.013 \cdot SEP}$

$assetvuln = 0.649$ $\quad$ $margvuln = 0.649$ $\quad$ $unitvuln = 0.603$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 2.036$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{strength}{\frac{Allocation}{TotalAllocation}}\right)\right) \qquad Attrition_2 = 0.679$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 0.679$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$floor(Attrition_{final}) = 0$$

Appendix B-4: ACES Gravity Bomb Attrition Example

The following is an example of the attrition of a number of assets by four unguided munitions.

Definition of Attrition Variables:

$SEP := 77$ $\quad$ $strength := 4$ $\quad$ $percentvisible := 0.80$ $\quad$ $scalingfactor := 1$

$Allocation := 10$ $\quad$ $TotalAllocation := 30$ $\quad$ $survivabilitypercent := 0$ $\quad$ $numassets := 5$

$assetvuln := 0.60^{0.013 \cdot SEP}$ $\quad$ $margvuln := 0.60^{0.013 \cdot SEP}$ $\quad$ $unitvuln := 0.55^{0.013 \cdot SEP}$

$assetvuln = 0.6$ $\quad$ $margvuln = 0.6$ $\quad$ $unitvuln = 0.55$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 3.163$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{Allocation}{TotalAllocation}\right)^{strength}\right) \qquad Attrition_2 = 1.054$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 1.054$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$floor\left(Attrition_{final}\right) = 1$$

Appendix B-5: ACES C/A Code S/A Off Attrition Example

The following is an example of the attrition of a number of assets by two guided munitions with C/A code access with S/A off.

Definition of Attrition Variables:

$SEP := 25$ $\quad strength := 2$ $\quad percentvisible := 0.80$ $\quad scalingfactor := 1$

$Allocation := 10$ $\quad TotalAllocation := 30$ $\quad survivabilitypercent := 0$ $\quad numassets := 5$

$assetvuln := 0.60^{0.013 \cdot SEP}$ $\quad margvuln := 0.60^{0.013 \cdot SEP}$ $\quad unitvuln := 0.55^{0.013 \cdot SEP}$

$assetvuln = 0.847$ $\quad margvuln = 0.847$ $\quad unitvuln = 0.823$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 4.726$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{Allocation}{TotalAllocation}^{strength}\right)\right) \qquad Attrition_2 = 1.575$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 1.575$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$\mathrm{floor}\left(Attrition_{final}\right) = 1$$

Appendix C: ACES Power Projection Examples

This example demonstrates the two-fold process of a power projecting satellite detecting a target and destroying the target once it's detected. The first example demonstates the satellite detecting and destroying the target. The second example shows the detection of a target that is not destroyed.

Example 1:

Definition of Detection Variables

$BuildupFactor := 0.80$ $\quad$ $ForestationFactor := 0.50$ $\quad$ $RuggednessFactor := 0.05$

$VisibilityFactor := 0.85$ $\quad$ $SensorFactor := 1$

Equation 4.7

$$FractionalPerception := BuildupFactor \cdot ForestationFactor \cdot RuggednessFactor \cdot VisibilityFactor \cdot SensorFactor$$

$$FractionalPerception = 0.017$$

The calculated fractional perception is greater than 0.001 so the target is detected.

Definition of Attrition Variables

$strength := 1$ $\quad$ $percentvisible := 0.85$ $\quad$ $scalingfactor := 1$ $\quad$ $numassets := 10$

$Allocation := 10$ $\quad$ $TotalAllocation := 30$ $\quad$ $survivabilitypercent := 0$

$assetvuln := 0.75$ $\quad$ $margvuln := 0.75$ $\quad$ $unitvuln := 0.65$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 3.108$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{Allocation}{TotalAllocation}^{strength}\right)\right) \qquad Attrition_2 = 1$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 1$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$\mathrm{floor}\left(Attrition_{final}\right) = 1$$

Appendix C: ACES Power Projection Examples

Example 2:

Definition of Detection Variables

$BuildupFactor := 0.80$ $\quad ForestationFactor := 0.50$ $\quad RuggednessFactor := 0.05$

$VisibilityFactor := 0.80$ $\quad SensorFactor := 1$

Equation 4.7

$$FractionalPerception := BuildupFactor \cdot ForestationFactor \cdot RuggednessFactor \cdot VisibilityFactor \cdot SensorFactor$$

$$FractionalPerception = 0.016$$

The calculated fractional perception is greater than 0.001 so the target is detected.

Definition of Attrition Variables

$strength := 1$ $\quad percentvisible := 0.80$ $\quad scalingfactor := 1$ $\quad numassets := 10$

$Allocation := 10$ $\quad TotalAllocation := 30$ $\quad survivabilitypercent := 0$

$assetvuln := 0.75$ $\quad margvuln := 0.75$ $\quad unitvuln := 0.65$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 2.925$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{\dfrac{strength}{Allocation}}{TotalAllocation}\right)\right) \qquad Attrition_2 = 0.975$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 0.975$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$floor\left(Attrition_{final}\right) = 0$$

Appendix D: ACES Intelligence Example

The following example demonstrates the detection process of IMINT and SIGINT satellites.

IMINT Detection:

Definition of Detection Variables

$BuildupFactor := 0.80 \quad ForestationFactor := 0.50 \quad RuggednessFactor := 0.05$

$VisibilityFactor := 0.05 \quad SensorFactor := 0.95$

Equation 4.8

$$FractionalPerception := BuildupFactor \cdot ForestationFactor \cdot RuggednessFactor \cdot VisibilityFactor \cdot SensorFactor$$

$$FractionalPerception = 0.00095$$

The calculated fractional perception is less than 0.001 so the target is not detected by the IMINT satellite.

SIGINT Detection:

Definition of Detection Variables

$MeanDuration := 0.5 \quad MinimumScanTime := 45 \quad MaximumVariation := 15$

$RandomNumber1 := rnd(1) \quad RandomNumber2 := rnd(1)$

Equation 4.9

$$Duration := -MeanDuration \cdot \ln(RandomNumber1)$$

$$Duration = 3.33499$$

Equation 4.10

$$CTime := 60 \cdot Duration - (MinimumScanTime + RandomNumber2 \cdot MaximumVariation)$$

$$CTime = 152.19967$$

Since CTime is greater than 0, the SIGINT satellite detects the unit and reports on its location.

Appendix E-1: ACES Weather Attrition Example (4 GPS Munitions)

This example shows the amount of attrition to a set of assets by four GPS guided munitions with P-Code.

Definition of Attrition Variables

$\text{strength} := 4$ $\quad$ $\text{percentvisible} := 0.90$ $\quad$ $\text{scalingfactor} := 1$ $\quad$ $\text{numassets} := 6$

$\text{Allocation} := 10$ $\quad$ $\text{TotalAllocation} := 50$ $\quad$ $\text{survivabilitypercent} := 0$ $\quad$ $\text{SEP} := 16$

$\text{assetvuln} := 0.55^{0.013 \cdot \text{SEP}}$ $\quad$ $\text{margvuln} := 0.55^{0.013 \cdot \text{SEP}}$ $\quad$ $\text{unitvuln} := 0.50^{0.013 \cdot \text{SEP}}$

$\text{assetvuln} = 0.883$ $\quad$ $\text{margvuln} = 0.883$ $\quad$ $\text{unitvuln} = 0.866$

Equation 4.2

$$\text{Attrition}_1 := \text{strength} \cdot \text{unitvuln} \cdot \text{scalingfactor} \cdot \text{numassets} \cdot \text{assetvuln} \cdot \text{margvuln} \cdot \text{percentvisible}$$

$$\text{Attrition}_1 = 14.582$$

Equation 4.3

$$\text{Attrition}_2 := \min\left(\left(\begin{matrix} \text{strength} \\ \text{Attrition}_1 \cdot \dfrac{\text{Allocation}}{\text{TotalAllocation}} \end{matrix}\right)\right) \qquad \text{Attrition}_2 = 2.916$$

Equation 4.4

$$\text{Attrition}_{\text{final}} := \text{Attrition}_2 - \text{survivabilitypercent} \cdot \text{Attrition}_2 \qquad \text{Attrition}_{\text{final}} = 2.916$$

Truncating $\text{Attrition}_{\text{final}}$ gives the number of assets destroyed:

$$\text{floor}\left(\text{Attrition}_{\text{final}}\right) = 2$$

Appendix E-2: ACES Weather Attrition Example (4 LGMs)

This example shows the amount of attrition to a set of assets by four laser guided munitions.

Definition of Attrition Variables

$strength := 4$ $\quad$ $percentvisible := 0.90$ $\quad$ $scalingfactor := 1$ $\quad$ $numassets := 6$

$Allocation := 10$ $\quad$ $TotalAllocation := 50$ $\quad$ $survivabilitypercent := 0$

$assetvuln := 0.975$ $\quad$ $margvuln := 0.975$ $\quad$ $unitvuln := 0.85$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 17.453$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{strength}{\frac{Allocation}{TotalAllocation}}\right)\right) \qquad Attrition_2 = 3.491$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 3.491$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$floor(Attrition_{final}) = 3$$

Appendix E-3: ACES Weather Attrition Example (Full LGM Load)

This example shows the amount of attrition to a set of assets by eight laser guided munitions.

Definition of Attrition Variables

$strength := 8$ $\quad percentvisible := 0.90$ $\quad scalingfactor := 1$ $\quad numassets := 6$

$Allocation := 10$ $\quad TotalAllocation := 50$ $\quad survivabilitypercent := 0$

$assetvuln := 0.975$ $\quad margvuln := 0.975$ $\quad unitvuln := 0.85$

Equation 4.2

$$Attrition_1 := strength \cdot unitvuln \cdot scalingfactor \cdot numassets \cdot assetvuln \cdot margvuln \cdot percentvisible$$

$$Attrition_1 = 34.907$$

Equation 4.3

$$Attrition_2 := \min\left(\left(Attrition_1 \cdot \frac{\frac{strength}{Allocation}}{TotalAllocation}\right)\right) \qquad Attrition_2 = 6.981$$

Equation 4.4

$$Attrition_{final} := Attrition_2 - survivabilitypercent \cdot Attrition_2 \qquad Attrition_{final} = 6.981$$

Truncating $Attrition_{final}$ gives the number of assets destroyed:

$$floor\left(Attrition_{final}\right) = 6$$

Appendix E-4: ACES Weather Attrition Example (LGMs with Reduced Visibility)

This example shows the amount of attrition to a set of assets by four laser guided munitions with reduced visibility.

Definition of Attrition Variables

$\text{strength} := 4$ $\quad$ $\text{percentvisible} := 0.25$ $\quad$ $\text{scalingfactor} := 1$ $\quad$ $\text{numassets} := 6$

$\text{Allocation} := 10$ $\quad$ $\text{TotalAllocation} := 50$ $\quad$ $\text{survivabilitypercent} := 0$

$\text{assetvuln} := 0.975$ $\quad$ $\text{margvuln} := 0.975$ $\quad$ $\text{unitvuln} := 0.85$

Equation 4.2

$$\text{Attrition}_1 := \text{strength} \cdot \text{unitvuln} \cdot \text{scalingfactor} \cdot \text{numassets} \cdot \text{assetvuln} \cdot \text{margvuln} \cdot \text{percentvisible}$$

$$\text{Attrition}_1 = 4.848$$

Equation 4.3

$$\text{Attrition}_2 := \min\left(\left(\text{Attrition}_1 \cdot \frac{\text{strength}}{\frac{\text{Allocation}}{\text{TotalAllocation}}}\right)\right) \qquad \text{Attrition}_2 = 0.97$$

Equation 4.4

$$\text{Attrition}_{final} := \text{Attrition}_2 - \text{survivabilitypercent} \cdot \text{Attrition}_2 \qquad \text{Attrition}_{final} = 0.97$$

Truncating Attrition_{final} gives the number of assets destroyed:

$$\text{floor}\left(\text{Attrition}_{final}\right) = 0$$

Appendix F: Example Space Surveillance Report

Type of Satellite	Side	Next Overflight Time (day/time)
Intel-1	Red	2/1235Z-2/1247Z
Weather	Blue	2/1423Z-2/1432Z
ELINT	Red	3/0604Z-3/0609Z
SIGINT	Red	3/1022Z-3/1030Z

Appendix G-1: Example Satellite Targeting and Destruction Results

The following is the result of the SLAM runs of the space surveillance and negation module. SLAM computes times in seconds but they have been translated here into hours. One hundred runs were made and the minimum, maximum, and mean times it took for each satellite to be on the target list and the times the satellite is finally destroyed were recorded.

Time till Satellite is Available for Targeting

	Mean Time (Hrs)	Minimum Time (Hrs)	Maximum Time (Hrs)
ELINT Satellite	11.06	10.42	16.17
IMINT Satellite	24.50	23.06	28.33
SIGINT Satellite	100.83	81.39	189.44

Time till Satellite is Destroyed

	Mean Time (Hrs)	Minimum Time (Hrs)	Maximum Time (Hrs)
ELINT Satellite	14.19	12.33	23.83
IMINT Satellite	27.44	24.83	35.56
SIGINT Satellite	131.39	96.94	235.56

Appendix G-2: Example Satellite Targeting and Destruction SLAM Control Statements

The following is the control statements for the SLAM network created to simulate the targeting and destruction of three satellites. Each variable used is defined.

```
GEN,PAYNE,SURVEILLANCE EXAMPLE,2/19/1996,100,Y,Y,Y/Y,Y,Y/10,132;
LIMITS,2,5,50;
;.    ATRIB(1) ==> INITIAL CREATE TIME
;.    ATRIB(2) ==> SATELLITE TIME BETWEEN OVERHEAD EVENTS (IN SEC)
;.    ATRIB(3) ==> SATELLITE DETECTION VULNERABILITY
;.    ATRIB(4) ==> SATELLITE OVERHEAD DURATION
;.    ATRIB(5) ==> SATELLITE VULNERABILITY TO ASAT
;.    XX(1), XX(2), XX(3)  ==> NUMBER OF SATELLITE DETECTS PER
SATELLITE
;.    XX(11), XX(22), XX(33) ==> NUMBER OF SATELLITE MISSES PER
SATELLITE
NETWORK;
INITIALIZE,,,N;
FIN;
```

Appendix G-3: Example Satellite Targeting and Destruction SLAM Network Statements

The following is the network statements for the SLAM network created to simulate the targeting and destruction of three satellites.

```
;FILE SURV2.NET, NODE LABEL SEED ZAAA
    RESOURCE/1,LASER,1;
;FILE SURV2.NET, NODE LABEL SEED ZAAA
;
```

CREATION OF SATELLITES

```
OVHD  CREATE,,,1,1;
    ACTIVITY;
    ACTIVITY,,,SIGI;
    ACTIVITY,,,IMIN;
```

ASSIGNMENT OF SATELLITE VALUES

```
ELINT ASSIGN,ATRIB(5)=0.65,XX(11)=1,ATRIB(4)=1200,ATRIB(3)=0.95,XX(1)=0,
ATRIB(2)=5700;
    ACTIVITY,3000,,DTCT;
SIGIN ASSIGN,ATRIB(5)=0.50,XX(22)=1,ATRIB(4)=600,ATRIB(3)=0.80,XX(2)=0,
ATRIB(2)=54900;
    ACTIVITY,15600,,DTCT;
IMINT ASSIGN,ATRIB(5)=0.60,XX(33)=1,ATRIB(4)=450,ATRIB(3)=0.85,XX(3)=0,
ATRIB(2)=6000;
    ACTIVITY,50700,,DTCT;
;
```

DETECTION TEST FOR SATELLITES

```
DTCT  GOON,1;
    ACTIVITY,ATRIB(4),UNFRM(0,1) .LE. ATRIB(3),CNTR;DTCT;
    ACTIVITY,ATRIB(2)+ATRIB(4),,MISS;
;
```

CALCULATION OF NUMBER OF MISSES

```
MISS  GOON,1;
    ACTIVITY,,ATRIB(3) .EQ. 0.95;
    ACTIVITY,,ATRIB(3) .EQ. 0.80,ZAAB;
    ACTIVITY,,ATRIB(3) .EQ. 0.85,ZAAC;
    ASSIGN,XX(11)=XX(11) + 1;
    ACTIVITY,,,DTCT;
ZAAB  ASSIGN,XX(22)=XX(22) + 1;
    ACTIVITY,,,DTCT;
ZAAC  ASSIGN,XX(33)=XX(33) + 1;
```

APPENDIX G-3: Satellite Targeting and Destruction SLAM Network Statements

```
ACTIVITY,,,DTCT;
;
CALCULATION OF NUMBER OF DETECTIONS

CNTR  GOON,1;
   ACTIVITY,,ATRIB(3) .EQ. 0.95;
   ACTIVITY,,ATRIB(3) .EQ. 0.80,CNT2;
   ACTIVITY,,ATRIB(3) .EQ. 0.85,CNT3;
CNT1  ASSIGN,XX(1)=XX(1) + 1,1;
   ACTIVITY,ATRIB(2),XX(1) .LT. 5,DTCT;
   ACTIVITY,ATRIB(2),,AST1;
CNT2  ASSIGN,XX(2)=XX(2) + 1,1;
   ACTIVITY,ATRIB(2),XX(2) .LT. 5,DTCT;
   ACTIVITY,ATRIB(2),,AST2;
CNT3  ASSIGN,XX(3)=XX(3) + 1,1;
   ACTIVITY,ATRIB(2),XX(3) .LT. 5,DTCT;
   ACTIVITY,ATRIB(2),,AST3;
;
DETERMINATION OF WHEN SATELLITE IS FIRST HANDED TO ASAT

AST1  COLCT,FIRST,ELINT ON LIST,,1;
   ACTIVITY,ATRIB(2),NRUSE(LASER) .EQ. 0,ASAT;
   ACTIVITY,ATRIB(2) + ATRIB(4),,DTCT;
;
AST2  COLCT,FIRST,SIGINT ON LIST,,1;
   ACTIVITY,ATRIB(2),NRUSE(LASER) .EQ. 0,ASAT;
   ACTIVITY,ATRIB(2) + ATRIB(4),,DTCT;
;
AST3  COLCT,FIRST,IMINT ON LIST,,1;
   ACTIVITY,ATRIB(2),NRUSE(LASER) .EQ. 0,ASAT;
   ACTIVITY,ATRIB(2) + ATRIB(4),,DTCT;
;
DETERMINATION OF SATELLITE DESTRUCTION

ASAT  AWAIT(1/1),LASER,,1;
   ACTIVITY,ATRIB(4),UNFRM(0,1) .LE. ATRIB(5);
   ACTIVITY,ATRIB(4)+ATRIB(2),,ZAAD;
   FREE,LASER;
   ACTIVITY,,,COUNT;
ZAAD  FREE,LASER;
   ACTIVITY,,,ASAT;
;
```

APPENDIX G-3: Satellite Targeting and Destruction SLAM Network Statements

COLLECTION OF STATISTICS

```
COUNT GOON,1;
    ACTIVITY,,ATRIB(3) .EQ. 0.95;
    ACTIVITY,,ATRIB(3) .EQ. 0.80,CLCT;
    ACTIVITY,,ATRIB(3) .EQ. 0.85,CLLT;
CLT1  COLCT,FIRST,ELINT DESTROY;
    ACTIVITY;
    COLCT,XX(11),ELINT MISSES;
    ACTIVITY,,,PAS1;
CLCT2 COLCT,FIRST,SIGINT DESTROY;
    ACTIVITY;
    COLCT,XX(22),SIGINT MISSES;
    ACTIVITY,,,PAS2;
CLLT3 COLCT,FIRST,IMINT DESTROY;
    ACTIVITY;
    COLCT,XX(33),IMINT MISSES;
    ACTIVITY,,,PAS3;
;
PAS1  COLCT,XX(1),ELINT DETECTS;
    ACTIVITY;
END   TERMINATE;
;
PAS2  COLCT,XX(2),SIGINT DETECTS;
    ACTIVITY,,,END;
;
PAS3  COLCT,XX(3),IMINT DETECTS;
    ACTIVITY,,,END;
    END;
```

Vita

Capt Robert Payne Jr. [redacted] Florida. He graduated from Niceville High School in 1987 and entered undergraduate studies at the University of South Alabama in Mobile, Alabama. He graduated with a Bachelor of Science degree in Mathematics and received his commission in June 1991. His first assignment was at Robins AFB as the Assistant Regional Director of Admissions for the States of Alabama and Georgia. After completing Undergraduate Space Training at Lowry AFB, he began his second assignment at Holloman AFB as a Space Systems Crew Commander. In August 1994, he entered the School of Engineering, Air Force Institute of Technology.

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In response to the increased influence of space forces on today's battlefield, several theater level models were analyzed for the presentaion of space forces. These models were the Extended Air Defense Simulation (EADSIM), the Joint Theater Level Simulation (JTLS), the Integrated Theater Engagement Model (ITEM), the Tactical Warfare Model (TACWAR), Thunder, Janus, and the Aggregate Level Simulation Protocol (ALSP). While ALSP is not a model but a simulation protocol connecting various models, it was studied because it appears to be the future of modeling. The consensus of the analysis was that space forces are virtually ignored by most of the models. The Air Force Command Exercise System (ACES) was chosed to determine how the effects of space forces can be implemented into theater level models. ACES is a discretes event combat simulation designed to support intermediate and senior service schools in teaching Air Force doctrine within the context of a theater warfare exercise. Its primary focus is to allow specific educational goals to be taught. This research focused on both the present modeling of space forces within widely used theater level models and a methodology to incorporate space forces into models that lack the influence of space

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